ornell University Announcements

College of Engineering

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1975–76

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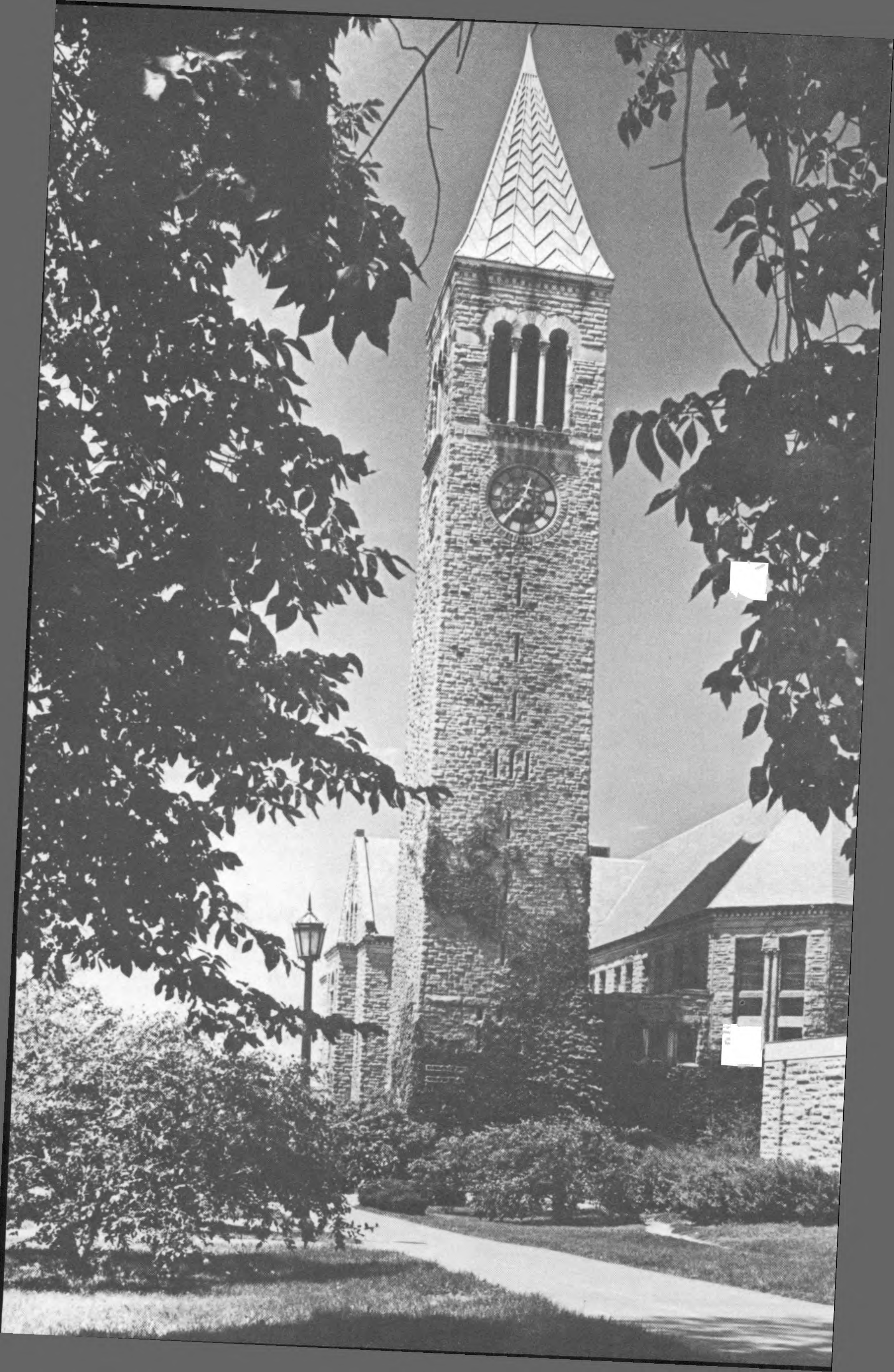


Announcements

Contents

The courses and curricula described in this Announcement, and the teaching personnel listed herein, are subject to change at any time by official action of Cornell University.

Further Information

Undergraduates

Prospective engineering students should write for a copy of the *Announcement of General Information*, which describes the University community in greater detail. *Engineering at Cornell*, an illustrated Announcement, has been prepared especially for pre-college students, and it too may be obtained by writing Cornell University Announcements, Day Hall, Ithaca, New York 14853.

Graduates

The *Announcement of the Graduate School* should be consulted for additional information regarding admission, financial aid, and degree requirements. Applicants for graduate study may also request the *Announcement of the Graduate School: Course Descriptions*. Also available is *Graduate Study in Engineering and Applied Science*, which contains information on various research programs and areas of study. These publications may be obtained by writing Cornell University Announcements, Day Hall, Ithaca, New York 14853.

Cornell Academic Calendar

1975–76

Registration, new students	Thursday, August 28
Registration, continuing and rejoining students	Friday, August 29
Fall term instruction begins	Monday, September 1
Thanksgiving recess:	
Instruction suspended, 1:10 p.m.	Wednesday, November 26
Instruction resumed, 7:30 a.m.	Monday, December 1
Fall term instruction ends, 1:10 p.m.	Saturday, December 6
Final examinations begin	Saturday, December 13
Final examinations end	Saturday, December 20
Registration, new and rejoining students	Thursday, January 22
Registration, continuing students	Friday, January 23
Spring term instruction begins, 7:30 a.m.	Monday, January 26
Spring recess:	
Instruction suspended, 1:10 p.m.	Saturday, March 27
Instruction resumed, 7:30 a.m.	Monday, April 5
Spring term instruction ends, 1:10 p.m.	Saturday, May 8
Final examinations begin	Monday, May 17
Final examinations end	Monday, May 24
Commencement Day	Friday, May 28

The dates shown in the Academic Calendar are subject to change at any time by official action of Cornell University.

In enacting this calendar, the University Senate has scheduled classes on religious holidays. It is the intent of Senate legislation that students missing classes due to the observance of religious holidays be given ample opportunity to make up work.

Cornell University

College of Engineering

In engineering, a constant factor is change—change so swift that the engineering student must be offered an education that is adaptable and flexible as well as specific. In its long history, the College of engineering at Cornell has consistently offered such education. Today the College combines undergraduate and graduate education with scientific and engineering research within the context of a diverse and distinguished university and is thereby continuing its tradition of providing both practical and sound general education.

Engineering courses have been taught at Cornell since the University was founded more than one hundred years ago. At that time, Cornell was regarded as a radical experiment in higher education, teaching subjects like engineering and agriculture as well as the humanities. The University's founder and first benefactor, Ezra Cornell, was convinced, however, that the classics and the more practical "mechanic arts" would thrive together and that the nation needed citizens educated in both. Mr. Cornell had had considerable experience in engineering work; for example, he laid the first telegraph line between Baltimore and Washington for Samuel F. B. Morse. Ezra Cornell made the first clear statement of what is now generally conceived to be the true university concept of higher education, when he said of his University, "I would found an institution where any person can find instruction in any study."

In addition to the College of Engineering, Cornell University has six other divisions to which secondary school graduates are admitted: College of Agriculture and Life Sciences; College of Architecture, Art, and Planning; College of Arts and Sciences; School of Hotel Administration; College of Human Ecology; and School of Industrial and Labor Relations. Graduate education at Cornell is administered by the Graduate School and by the professional or graduate divisions in law, veterinary medicine, business and public administration, nursing, and medicine. All but the last two divisions (which are in New York City) are in Ithaca, New York, on a campus that is generally regarded as one of the most beautiful in the United States.

Engineering students at Cornell, whether graduate or undergraduate, are not only a part of a distinguished engineering college but also a part of the larger University; they may, of course, draw upon the course offerings of other divisions of Cornell. Undergraduate students have a choice of a wide range of specialty programs which can be adapted to meet particular educational and career goals, or they can arrange individual curricula.

Cornell has produced many engineering firsts: It developed the first undergraduate electrical engineering program in the nation and pioneered in the early development of curricula in industrial engineering, mechanical engineering, and engineering physics. Cornell was the first to award graduate degrees in engineering—the degree of Civil Engineer in 1870 and the first doctorate in civil engineering in 1872. The latter was the first Ph.D. awarded at Cornell in any graduate study. In 1885, Cornell granted the first Ph.D. in electrical engineering in the nation, and in 1886, one of the first major national scientific fraternities, Sigma Xi, was founded at Cornell.

Today, approximately 2,200 undergraduate engineers are enrolled in the various schools and departments of the College of Engineering. In addition, about 650 full-time students are working on advanced degrees in a wide range of engineering and applied science areas. Some two hundred engineering faculty members are complemented by the faculties in the University's mathematics and science departments.

The Cornell College of Engineering believes that engineering education has an expanded role in today's complex society. Because so many of the urgent problems of the world have technological components, some knowledge of science and technology is important for everyone. Also, the increasing interaction between engineering and other aspects of modern life requires a broadly based education for professional engineers. The programs in engineering at Cornell are designed to meet these needs—to provide the foundation for effective work in a variety of non-engineering fields, as well as a wide range of scientific and engineering disciplines.

Organization of the College

The College of Engineering offers degree programs at each of the following levels: Bachelor of Science, Master of Engineering, Master of Science, and Doctor of Philosophy. To carry out the aims of each of these degree programs, the faculty of the College of Engineering is organized into schools, departments, and graduate fields.

Generally, a school or department is responsible for definition and subsequent supervision of the undergraduate curriculum in its area of engineering. In addition, the faculty of a school is responsible for the Master of Engineering degree program.

For Master of Science and doctoral programs, the University faculty is organized into graduate fields. Those fields associated with the faculty of the College of Engineering are listed below under Master of Science and Doctor of Philosophy degrees.

Facilities

Buildings and Laboratories

A complex of modern buildings, most of them on the Engineering Quadrangle, provides accommodations for engineering teaching and research. Several of these buildings have been gifts from distinguished Cornell alumni.

Carpenter Hall houses administrative offices and the Engineering Library.

Bard Hall contains most of the laboratories and classrooms of the Department of Materials Science and Engineering.

Clark Hall serves the University's Department of Physics and houses facilities of the School of Applied and Engineering Physics. It is located on the campus of the College of Arts and Sciences.

Grumman Hall, adjacent to Upson Hall, houses some of the facilities of the Sibley School of Mechanical and Aerospace Engineering.

Hollister Hall houses the School of Civil and Environmental Engineering.

Kimball Hall is used for mechanical engineering laboratories and also houses the Department of Geological Sciences.

Olin Hall houses the School of Chemical Engineering. The Division of Basic Studies, the Engineering Advising and Counseling Center, the Engineering Registration Offices and the headquarters of the College Program also are located there.

Phillips Hall is the headquarters of the School of Electrical Engineering.

Thurston Hall facilities are used by the Department of Theoretical and Applied Mechanics and by the Department of Structural Engineering of the School of Civil and Environmental Engineering.

Upson Hall houses the administrative offices and some of the facilities of the Sibley School of Mechanical and Aerospace Engineering; the School of Industrial Engineering and Operations Research; the University's Department of Computer Science; and headquarters of the Laboratory of Plasma Studies. A remote terminal of the University's central computing facility, located in Upson Hall, provides convenient access for engineering students and professors.

Ward Laboratory of Nuclear Engineering houses special equipment including TRIGA and low-power reactors, a gamma irradiation cell, and a low-energy ion accelerator.

More detailed descriptions of facilities for each of the instructional areas in the College may be found within the section Areas of Instruction.

Library Resources

The Engineering Library, in Carpenter Hall, contains approximately 150,000 books and periodicals, a collection which reflects the needs of the many schools and departments of the College of Engineering. Among the specialized holdings of the Engineering Library are a full depository collection of the United States Atomic Energy Commission and a subscription collection of the Rand Corporation publications (established in 1953). For patent research, the library maintains sets of the Official Patent Gazette of the United States Patent Office and the Canadian Patent Office Record (patent abstracts).

Allied and supporting literature in the basic sciences is available in the Edna McConnell Clark Library (physical sciences) in Clark Hall and in the Mathematics Library in White Hall. The major collection in the biological sciences is found in the Albert R. Mann Library, and that for the geological sciences in the John M. Olin Library. The total library resources of the University include more than four million volumes.

Academic Programs

Bachelor of Science Degree

The undergraduate degree of Bachelor of Science is granted by the College of Engineering upon the successful completion of a four-year course of study, which includes forty courses with at least 126 credits. Students obtain this degree by spending two years in the Division of Basic Studies preparing for entry into one of seven upperclass *Field Programs* or a *College Program*, in which they will spend two additional years completing the requirements for the undergraduate degree. (An exception is the program in agricultural engineering, which is administered jointly by the College of Engineering and the College of Agriculture and Life Sciences. Students are enrolled in the College of Agriculture and Life Sciences for the first three years, and in the College of Engineering for the fourth year.)

Undergraduate Engineering Curricula

The underclass curriculum in the Basic Studies program consists of five courses, each of four semesters; the twenty courses are distributed as follows:

	Credits
Two introductory engineering courses	6
Four mathematics courses	15
Three physics courses	12
One chemistry course	3
Two natural science or social science elective courses	6
Four engineering core science elective courses	12
Four liberal studies elective courses	12

After completing the Basic Studies program, the engineering student enters the Field Program of his or her choice, or the College Program. The upperclass Field Programs include the following twenty courses:

	Credits
Four liberal studies elective courses, two of which must be at an upper division level (300 or 400 level courses)	12
Two free elective courses	6
Two technical elective courses	6
Twelve field-designated courses	36

Upperclass students in the College Program have similar requirements.

Field Programs available for the junior- and senior-year specialization (described in the section of Areas of Instruction) are offered in seven areas:

Chemical Engineering
Civil and Environmental Engineering
Electrical Engineering
Engineering Physics
Industrial Engineering and Operations Research
Materials Science and Engineering
Mechanical Engineering

The College Program (see p. 38) is a flexible and individually structured curriculum which is offered to accommodate educational objectives not served by one of the Field Programs. Bioengineering-oriented curricula are available in most Field Programs and in the College Program to accommodate the interests of students who plan to apply their engineering skills in biological areas.

Each undergraduate student has the opportunity to select numerous elective courses. Free electives may be chosen from the offerings of any division of the University. Suitable natural science electives, social science electives, engineering core science electives, and liberal electives are prescribed by the Core Curriculum Committee of the faculty. Suitable technical electives are prescribed by the faculties of each upperclass field. For information on particular courses of interest, students and their advisers consult other Announcements, most frequently those of the College of Arts and Sciences, the College of Agriculture and Life Sciences, the School of Industrial and Labor Relations, and the College of Human Ecology. A listing of subjects of study offered in the various units of the University, and the schools or colleges that offer them, is given in the *Announcement of General Information*.

The Engineering Cooperative Program

The basic premise of the Engineering Cooperative Program at Cornell is that industry can play a major role in a student's education by providing work assignments appropriate to his or her interests and training. Under this Program undergraduate engineering students can obtain almost a full year of professional experience without extending the date of their graduation. More than 600 Cornell engineers have participated in this Program since its inception in 1947.

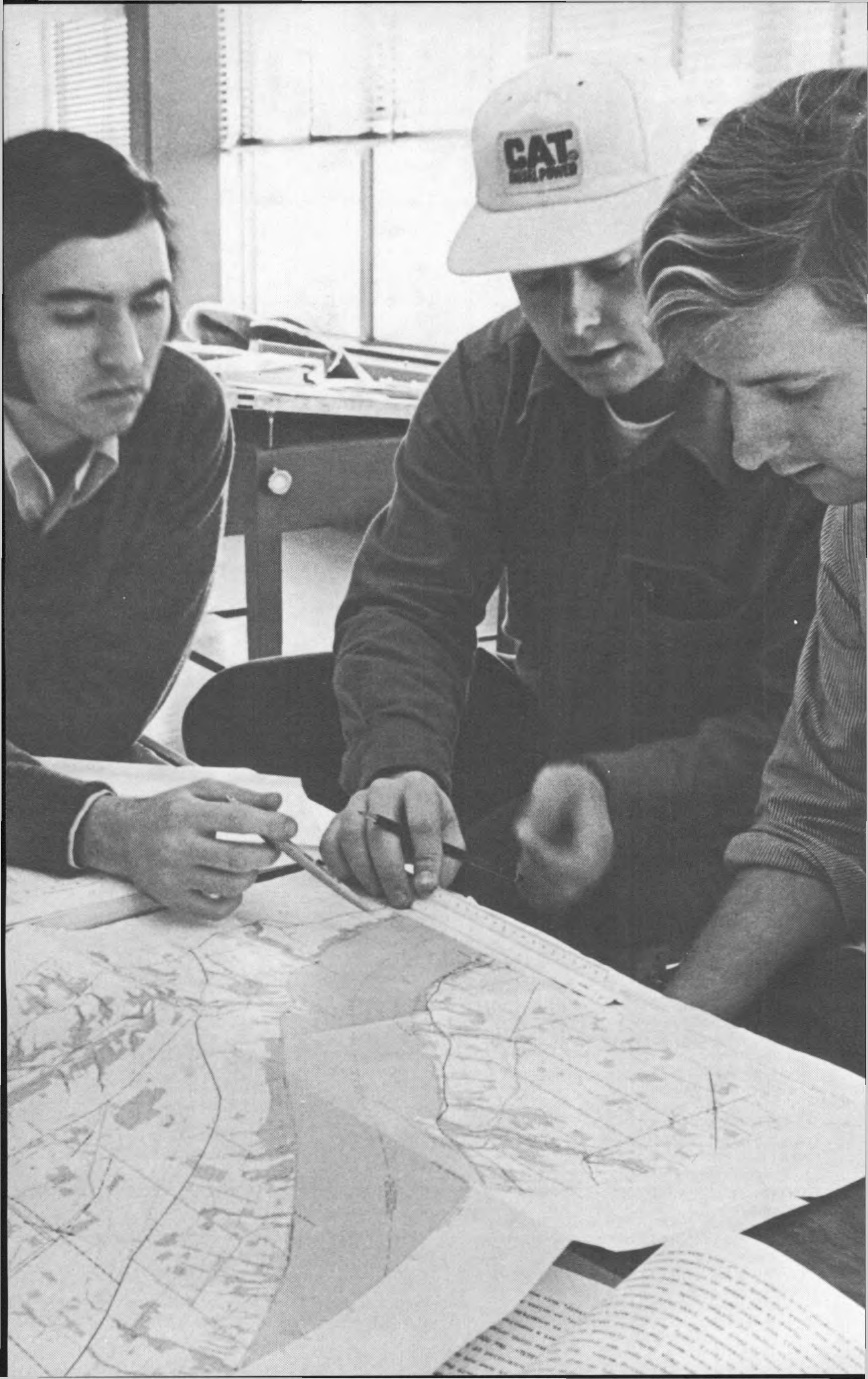
Students enrolled in the Program spend alternating periods in college and in industry after the sophomore year. By utilizing the three summers that follow completion of the sophomore year, three work periods, totaling nearly a calendar year, are provided. On the following schedule they are designated I, II, and III, respectively.

Summer	Fifth Term Courses
Fall (Junior Year)	Industry I
Spring (Junior Year)	Sixth Term Courses
Summer	Industry II
Fall (Senior Year)	Seventh Term Courses
Spring (Senior Year)	Eighth Term Courses
Bachelor of Science Degree	
Summer	Industry III

By the end of the summer following graduation, the student is ready to accept a professional position or begin graduate work. Graduate study leading to the Master of Engineering degree, for example, can begin in the fall term.

While on a work assignment, the student earns a substantial salary and gains industrial experience that complements classroom knowledge and facilitates the transition from college to industry. Because the Program emphasizes the development of the individual and his or her abilities, the student works for only one organization during the three industry periods. However, neither the student nor the organization is obligated in any way after completion of the Program. Having participated in the Program, graduates can expect their initial level of responsibility and salary to be greater than they might otherwise receive.

Organizations participating in the Engineering Cooperative Program include the following; American Electric Power Service Corporation; AVCO Everett Research Laboratory, Inc.; The Badger Company, Inc.; Bovay Engineers, Inc.; Chevron Research Company; Chicago Bridge & Iron Company; Chicago Pneumatic Tool Company; Corning Glass Works; The Dow Chemical Company; The DuPont Company; Eastman Kodak Company; Eaton Corporation; Emerson Electric Company; Exxon Corporation; Foster Wheeler Corporation; General Electric Company (Electronics Laboratory, Gas Turbine Products Division, Generator Division, and Transportation Systems Business Division); General Motors Corporation (Harrison Radiator Division); Greeley and Hansen; Department of Health, Education and Welfare (Social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Security Administration); Hewlett-Packard Company (Medical Electronics Division and New Jersey Division); Howard, Needles, Tammen & Bergendoff; International Business Machines Corporation; Johnson & Johnson; Joseph S. Ward, Inc.; Monsanto Company; Nordson Corporation; Olin Corporation (Chemicals Group); Pittsburgh-DesMoines Steel Company; The Procter & Gamble Company (Engineering Division and Management Systems Division); Raytheon Company; Sanders Associates, Inc.; Scott Paper Company; SI Handling Systems, Inc.; Smith-Corona Laboratory; Structural Dynamics Research Corporation; Supermarkets General Corporation; Turner Construction Company; and Xerox Corporation.

Admission to the Program is open to any fourth-term student who has chosen a Field Program in Chemical Engineering, Civil and Environmental Engineering, Electrical Engineering, Engineering Physics, Industrial Engineering and Operations Research, or Mechanical Engineering, and who meets the following requirements: (1) a sound scholastic performance at the time of admission to the Program; and (2) an invitation from one of the participating organizations based on an individual review.

Further information about the Program may be obtained from the Engineering Cooperative Program Office, 138 Upson Hall.

Program for Minority Students

Cornell University administers a variety of special opportunity programs designed to provide financial assistance and other forms of assistance to (1) minority students and (2) low-income students meeting program guidelines. The emphasis of these special programs is to aid in increasing representation of students from minority groups present in New York State who historically have been underrepresented in higher education. However, participation is also available to those residing outside New York State. For details, prospective students should consult the *Guide for Candidates* which accompanies each undergraduate application or will be sent upon request by the Office of Admissions, 410 Thurston Avenue, Ithaca, New York 14853.

Of the approximately 2,200 College of Engineering undergraduates, about 155 are currently enrolled in the Program for Minority Students, and efforts are being made to increase the proportion. Because minority students often have deficiencies in preparatory work and other background handicaps, the College offers special programs to help them succeed in their studies and prepare for professional careers.

Among available support services is an orientation program, offered during the summer before freshman matriculation, which is designed to strengthen skills in mathematics and science. During the regular academic year, special advising and counseling services are offered in coordination with the University's Committee for Special Educational Programs (COSEP). Tutoring and other assistance is available as may be needed on an individual basis.

In addition, two programs are offered to help orient the students to engineering as a profession. One brings practicing minority-group engineers to the campus in a special series of lectures and discussions, and the other provides sophomores with the opportunity to participate in on-the-job industrial experience for a short period of time between academic terms.

Admission of minority-group students, as of all applicants, is considered partly on the basis of academic performance in high school and of scores on college entrance examinations and achievement tests. Test scores are analyzed in terms of the applicant's environmental background. Subjective information from Cornell alumni, school guidance counselors, community agency personnel, and other concerned individuals is also considered.

Substantial financial assistance, in the form of scholarships and loans, is available to minority students (see p. 17).

Study in France: an Exchange Program

Junior engineering students are eligible to participate in a student exchange program that the College of Engineering operates with several engineering schools in France.

Collectively, these schools essentially cover the subjects available at Cornell, so that any Cornell engineering student, regardless of the Field Program or College Program he wishes to pursue, can plan a suitable curriculum to include the junior year abroad. The only limitation is the number of places available: only a few Cornell students can be placed each year in any one of the French schools. Application should be made during the sophomore year.

The program was begun a number of years ago with the Ecole Nationale Supérieure de Mechanique et d'Aérotechnique in Poitiers (about 150 miles southwest of Paris). This is a small school of about 170 students, closely associated with a large university in Poitiers and also part of the national system of engineering schools, the Ecole Nationale Supériere d'Ingénieurs (ENSI). More recently, the exchange has been extended to the Institut Polytechnique de Grenoble, a group of five ENSI schools in Grenoble.

Because the Cornell exchange students live in small groups among French students and take their instruction entirely in French, facility in the language is essential. Some of the Cornell participants have spent one or two months during the preceding summer at a language school in France.

Further information about the program may be obtained through the Engineering Advising and Counseling Center, 170 Olin Hall.

Dual Undergraduate Degree Option

It is possible to have dual registration in the College of Engineering and the College of Arts and Sciences and to earn both a Bachelor of Science degree in the College of Engineering and a Bachelor of Arts degree in the College of Arts and Sciences in five years. A student who wishes to follow this plan may register in either college as a freshman and take the usual freshman curriculum prescribed by that college. Students should explore the dual degree requirements during the first or second year so that they will be able to plan their curriculum and embark on the dual program during the second or third year.

A student in the program is registered in both colleges, has faculty advisers from both colleges, and takes a course program arranged jointly by both advisers. The degree requirements of both colleges—such as the core courses and upperclass field requirements in the College of Engineering and the distribution and language requirements in the College of Arts and Sciences—must be satisfied. Generally, an engineering Field Program or the engineering College Program can be combined with any major in arts and sciences. Dual majors that are closely related require special planning.

The program is intended for superior students. Those requesting dual registration must have a cumulative average of at least 2.7 on admission to the dual program and must maintain it.

Engineering students who are interested in the dual degree program should contact Associate Dean M. S. Burton, 170 Olin Hall.

ROTC (Officer Education)

As a land-grant institution chartered under the Morrill Act of 1862, Cornell has offered instruction in military science for more than one hundred years. The University provides this instruction through the Reserve Officers Training Corps programs of the three military departments: the Army, the Navy, and the Air Force.

The ROTC programs offer students the opportunity to earn commissions while completing their education. To obtain a commission in one of the armed services, a student must complete a two-year, three-year, or four-year course of study in an ROTC program and must meet certain physical standards. Upon graduation, the student receives a commission and serves a tour of active military service.

Further information is provided in the *Announcement of Officer Education*, which may be obtained by writing to Cornell University Announcements, Day Hall. Interested individuals are also directed to the appropriate ROTC office in Barton Hall.

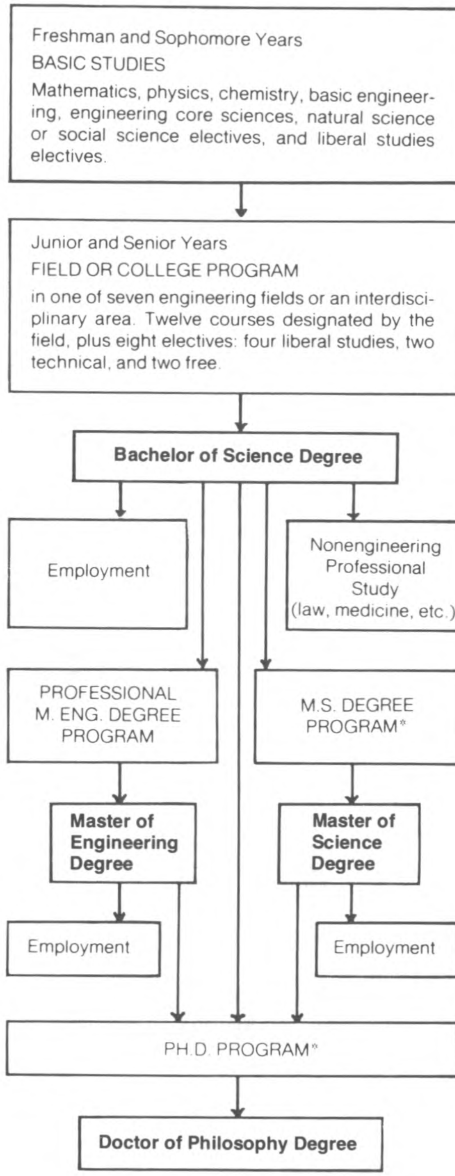
Preparation for Graduate Study

The Bachelor of Science degree may be the terminal point in the formal education of some students; however, most continue their studies beyond this level.

Many graduates choose to continue work in their undergraduate field of specialization, and apply for admission to the College's one-year professional Master of Engineering degree program. Others apply for programs leading to the degrees of Master of Science or Doctor of Philosophy in engineering or applied science disciplines. These graduate degree programs at Cornell are described briefly below.

Some baccalaureate graduates of the College of Engineering undertake graduate or professional study in non-engineering areas such as education, law, business, public administration, city and regional planning, medicine, and various branches of science and mathematics.

Summary of Programs and Options in Cornell Engineering Education



*Consult the *Announcement of the Graduate School* for detailed requirements for the M.S. and Ph.D. degree programs.

Master of Engineering Degree

Graduates intending to prepare for professional engineering careers generally seek the professional degree of Master of Engineering (with field designation). At Cornell this one-year program is integrated with the undergraduate engineering program; after receiving their baccalaureate degrees, many students apply to continue for the fifth year. Applications from engineering and applied science graduates of other institutions also are encouraged. Admission requirements are described below.

Upon completion of the program, students can either accept employment in engineering or applied science or elect to apply for further graduate training in an appropriate Ph.D. program.

The degree may be taken in any of these areas:

Aerospace Engineering (see p. 56)
Agricultural Engineering (see p. 28)
Chemical Engineering (see p. 34)
Civil Engineering (see p. 36)
Electrical Engineering (see p. 46)
Engineering Mechanics (see p. 64)
Engineering Physics (see p. 31)
Industrial Engineering (see p. 51)
Materials Engineering (see p. 54)
Mechanical Engineering (see p. 60)
Nuclear Engineering (see p. 61)

The professional degree requires a minimum of thirty credit hours of graduate-level work in the principles and practices of the specific field. It does not require the presentation of a thesis. It does, however, require completion of an engineering design project that may be worked on individually or in groups of up to four students, and submission of a formal report on the project. The program also requires completion of a curriculum of related technical courses, differing in content among the several professional fields. Each curriculum includes some prescribed and some elective courses, with considerable flexibility to permit adaptation to the special needs of the individual student. This program is generally completed in one academic year, but can be extended upon request to include the following summer term; in that case, a September degree is conferred.

Admission

A student with a baccalaureate degree from an accredited engineering program or its equivalent, in an area of engineering or science that is deemed appropriate for the proposed field of study, may become a candidate for the professional degree of Master of Engineering (with field designation). Cornell graduates will generally be admitted if they have cumulative grade-point averages of at least 2.5 and/or if they have demonstrated by their performances in their major fields that they have the ability to be successful in graduate study. A petition is required if the grade-point average is below 2.5. Graduates of schools other than Cornell must provide evidence of undergraduate preparation equivalent to that provided by a Cornell undergraduate engineering degree: a transcript, two letters of recommendation, and a statement of academic purpose. A candidate who is admitted with an undergraduate background that is judged inadequate must make up the deficiencies in addition to fulfilling the regular course requirements for the degree.

While there is no specific deadline for the receipt of applications, early submission is recommended, especially if the candidate wishes to apply for financial aid. Application forms are available through the various program chairmen or from the Office of the Graduate Professional Engineering Programs, 221 Carpenter Hall.

Financial Aid

Applicants for the professional degree programs who wish to apply for financial aid should complete a special application form available along with the admission application. The deadline for regular financial aid applications is February 1. There is also a financial aid early decision plan for prospective Master of Engineering students who are enrolled in undergraduate engineering programs at Cornell. The application deadline for this plan is November 15; the awards are announced on December 13.

It should be noted that candidates must be admitted into the program before their applications for financial aid are reviewed. For this reason, it is recommended that admission applications be filed as early as possible.

Master of Science and Doctor of Philosophy Degrees

The general degrees of Master of Science and Doctor of Philosophy are oriented toward students seeking academic or research careers. They require work in both major and minor areas of study, and submission of a thesis on research conducted under the direction of a faculty member. These programs are administered by the Graduate School, and prospective applicants should consult the *Announcement of the Graduate School* for more complete information.

Programs of study are organized under graduate fields; in the areas of engineering and applied science, these fields generally coincide with the respective schools or departments of the College of Engineering. Fields that may be of interest to engineering students are listed below, with associated areas of specialization.

Aerospace Engineering: Aerospace Engineering, Aerodynamics

Agricultural Engineering: Agricultural Engineering, Agricultural Structures, Agricultural Waste Management, Electric Power and Processing, Power and Machinery, Soil and Water Engineering

Applied Mathematics

Applied Physics

Chemical Engineering: Biochemical Engineering, Chemical Engineering (General), Chemical Microscopy, Chemical Processes and Process Control, Materials Engineering, Kinetics and Transport Processes

Civil and Environmental Engineering: Aerial Photographic Studies, Environmental Systems Engineering, Geodetic and Photogrammetric Engineering, Geotechnical Engineering, Hydraulics and Hydrology, Sanitary Engineering, Structural Engineering, Structural Mechanics, Transportation Engineering, Water Resource Systems

Computer Science: Computer Science, Information Processing, Numerical Analysis, Theory of Computation

Electrical Engineering: Electrical Engineering, Electrical Systems, Electrophysics

Geological Sciences: Economic Geology; Engineering Geology; Environmental Geology; Geobiology; Paleontology and Stratigraphy; Geochemistry, Mineralogy, and Petrology; Geomorphology; Geophysics; Geotectonics and Structural Geology; Marine Geology; Physical Geography; Seismology

Materials Science and Engineering: Materials Science, Materials Engineering

Mechanical Engineering: Machine Design, Materials Processing, Thermal Power, Thermal Processes

Nuclear Science and Engineering: Nuclear Engineering, Nuclear Science

Operations Research: Applied Probability and Statistics, Industrial Engineering, Information Processing, Operations Research, Systems Analysis and Design

Theoretical and Applied Mechanics: Fluid Mechanics, Mechanics of Materials, Solid Mechanics, Space Mechanics

Water Resources

Further information on these graduate fields may be found in the illustrated Announcement, *Graduate Study in Engineering and Applied Science* (see p. 4), which includes descriptions of academic programs, professional opportunities in the fields, facilities available at Cornell, current research projects, and faculty members and their research interests. Prospective students whose interests are already well defined are invited to communicate with the appropriate graduate faculty representative.

Admission

Applicants must hold a baccalaureate or equivalent degree from a college or university of recognized standing. Students who do not completely meet entrance requirements may be admitted as provisional candidates or without candidacy, according to previous preparation, but in all cases they must hold a baccalaureate or equivalent degree.

Financial Aid

Financial aid to graduate students is available in several forms: fellowships and scholarships; research or teaching assistantships; residence hall assistantships; and loans. Applicants who wish to be candidates for financial aid should consult the *Announcement of the Graduate School* and make application to the dean of the Graduate School.

Continuing Education Activities

The Office of Continuing Education of the College of Engineering provides special programs for engineers and scientists in industry, research institutes, private practice, governmental agencies, and colleges and universities. The programs include in-plant courses for firms in the Ithaca area; short courses and workshops in various technical subjects; and programs for specific industries. No academic credit is given for most of these programs.

The recent installation of television equipment in a classroom at the College has made possible a new program of off-campus courses utilizing videotapes of regular on-campus classes and lectures. Both credit and noncredit courses are available.

Further information about any of these programs may be obtained from the Office of Continuing Education, Carpenter Hall.

Admission

It is the policy of Cornell University actively to support equality of educational opportunity. No student shall be denied admission to the University or be discriminated against otherwise because of race, color, creed, religion, national origin, or sex.

Freshman Admission

The Office of Engineering Admissions in Carpenter Hall is the focal point in the College for the admission of freshman and transfer students and for the administration of the engineering financial aid funds.

Detailed information concerning the procedures of undergraduate admission is given in the *Announcement of General Information* and in the *Guide for Candidates* (included with each application form). Important dates for applicants include:

Admission Applications due: Regular, February 15; Early Decision Plan, November 1.

Admission decisions announced: Regular, as decisions are made in February, March, and the first half of April; Early Decision Plan, December 1 (except that those who are considered on the basis of November College Entrance Examination Board Scholastic Aptitude Tests will be notified by mid-December — the scores are not received by the Office of Engineering Admissions until early in December).

Financial aid applications due: Regular, January 15; Early Decision Plan, November 1.

Financial aid decisions announced: Regular, by mid-April; Early Decision Plan, December 1.

Date by which applicant must advise Cornell of his or her decision (for admission and financial aid): Regular, May 1; Early Decision Plan, applicants will be advised of date.

Secondary School Credits

Sixteen units of college-preparatory subjects are required for admission. A unit is one year of study, made up of approximately 120 clock hours of classroom work. The sixteen required units may be widely distributed, but prospective applicants are strongly encouraged to concentrate much of their studies in mathematics and the physical sciences. The following six units must be included; four of mathematics, one of physics, and one of chemistry. Normally, the remaining ten units are in English, foreign language, history, social science, and natural science or life sciences.

Minimum adequate mathematics preparation is two years of algebra, one year of geometry, and one year of precalculus mathematics, such as advanced algebra, solid geometry, or trigonometry. The mathematics units may be taken as separate courses or may be included in four units of comprehensive college-preparatory mathematics.

Prospective students who are interested in bioengineering are advised strongly to complete at least one unit of biology.

Applicants with special or unusual preparation which may not meet the above specifications are urged to communicate with the director of engineering admissions, 221 Carpenter Hall.

College Entrance Examinations

Each candidate is required to take standardized college admissions tests so that scores can be considered by the Engineering Admissions Committee. There are two available alternatives.

One alternative is for the student to take the College Entrance Examination Board Scholastic Aptitude Test (SAT), and in addition the Achievement Tests in mathematics (Level I or Level II) and in chemistry or physics. These *must* be taken not later than January of the last year in secondary school. Generally, it is recommended that the Achievement Test in science be taken in May of the junior year, in that science in which the applicant is then enrolled. However, the Engineering Admissions Committee will consider a science Achievement Test that is taken in December or January of the senior year for a course completed in the junior year, or earlier, or for a course currently in progress. Under these circumstances, test results are not expected to be as high as the results of tests taken at the time of completion of a full year's work. *Applicants should not defer this required test until March or May of the senior year, for results would be received too late to be useful to the committee.*

The other alternative is to submit American College Testing program (ACT) scores. The ACT tests should be taken not later than the December test date.

Factors Determining Admission

Three factors are considered in the review of each candidate. The first factor is academic and includes, in addition to the college entrance examination results, the applicant's high school grades, rank in class, and other available academic data. The second and third factors are personal qualities and demonstration of a well-considered desire and well-founded commitment to study engineering.

Personal qualities that are considered may include leadership capabilities and intellectual creativity. Significant participation in extracurricular activities and recommendations by counselors may also be considerations. A student's commitment to engineering is evidenced by the extent of his or her investigation of the field and understanding of the implications of an undergraduate professional education.

The admissions committee tries to judge whether a student has the maturity and the study and work habits that are necessary for success in an engineering curriculum. Superior grades or high college entrance examination scores are in themselves no guarantee of success, nor are they alone a guarantee of admission.

Advanced Placement

Normally about one-half of the students entering the College of Engineering as freshmen receive advanced placement and credit toward the B.S. degree. This is earned most often in mathematics, physics, and chemistry, but it is also received in other subjects such as biological science, history, and foreign languages. In some cases it is possible for students to complete the undergraduate degree requirements in less than the usual four years (see also p. 20).

Advanced placement credit may be obtained by entering freshmen in three ways. The most common way is by achieving high standing in College Entrance Examination Board Advanced Placement tests. A second way is by performing well on advanced placement examinations that are given by a number of Cornell departments during the fall orientation period, or by meeting certain departmental requirements. Finally, secondary school students may receive Cornell credit for course work completed at local, accredited colleges and universities. Normally, credit toward the Cornell degree will be awarded if the following conditions are met: (1) The college course was not taken to satisfy secondary school graduation requirements; (2) the course is registered on an official transcript from the college or university; (3) the course is applicable to some portion of the Cornell undergraduate engineering curriculum.

The requirements for advanced credit in four subject areas are summarized below.

Mathematics. If possible, secondary school students should take one of the two College Board Advanced Placement examinations in mathematics during the senior year. For engineering students, a grade of 3 or higher on the AB examination, or of 2 or 3 on the BC examination earns advanced placement credit for Mathematics 191 and placement in Mathematics 192. A grade of 4 or 5 on the BC examination will result in advanced placement credit for Mathematics 191 and 192 and placement in Mathematics 293.

Students who did not take one of the College Board examinations, or who took one but received less advanced placement than they think they should have, may take a special placement examination which is given by the Cornell Department of Mathematics just before the beginning of classes in the fall.

Physics. Entering freshmen who have scored well on a College Board Advanced Placement examination in physics may be granted advanced placement credit for Physics 112, the first of the required three-course sequence in physics. It should be noted, however, that the mathematics prerequisites for physics courses must be satisfied, and that an accelerated program in physics is therefore contingent on advanced placement in mathematics.

Suitably prepared students who did not have the opportunity to take the College Board examination may take instead a special test administered by the Cornell Department of Physics in the fall (and also in June for students enrolled in the Cornell Summer Session). Suitable preparation for this departmental test consists of two years of secondary school physics.

Chemistry. A score of 4 or 3 on the College Board Advanced Placement examination in chemistry earns three hours of advanced placement credit for Chemistry 207, and a score of 5 earns an additional four hours of credit for Chemistry 208. It is also possible for a student to achieve advanced placement credit by passing a special examination for Chemistry 207-208. Arrangements for taking this examination must be made with the Department of Chemistry. Students who earn one term of advanced placement in chemistry are not required to take additional chemistry unless they intend to major in chemical engineering.

Biological Sciences. Engineering students who are planning to take advanced courses in biological sciences and who achieve a score or 3 or 4 on the College Board Advanced Placement examination in biology will be placed in a special honors section of Biological Sciences 101-102. Students who receive a score of 5 will be given six hours of advanced placement credit in biology, which may be used to satisfy the natural sciences requirement.

Modern Foreign Languages. Students who receive a grade of 700 or above on the College Board reading examination are eligible to take the Advanced Standing Examination administered by the Cornell Department of Modern Languages and Linguistics. Students will then be placed in the appropriate language course on the basis of their performance in this examination. Advanced placement credit is granted as follows: For high school work, credit is granted only for the equivalent of 200-level Cornell language courses. Credit is awarded according to performance in the College Board Advanced Placement Examination (a score of 4 or 5 equals three credits), Cornell's Advanced Standing Examination, or special examination. A recommendation for credit is forwarded by the appropriate language and linguistics faculty member to this College.

Up to eight credits of advanced placement in modern foreign language may be counted as liberal elective credit toward the Bachelor of Science degree in the College of Engineering.

Transfer Admission

The College of Engineering welcomes inquiries about transfer opportunities for students who are currently attending other four-year or two-year colleges and universities. Each year the College matriculates approximately fifty new transfer students, and it is actively seeking to increase this number. Interested students are invited to communicate with the Chairman, Transfer Admissions Committee, 221 Carpenter Hall.

Transfer students are admitted at the junior-year level or below. Because the transfer student must satisfy the same degree requirements as all other Cornell engineers, admission is usually offered only to those candidates who have excelled in academic programs comparable, both in course content and rigor, to the College's own curriculum. The Cornell engineering curriculum for the freshman and sophomore years is discussed under Division of Basic Studies (see p. 21).

Students who are accepted for transfer admission but are found deficient in the specific course work required for a given level of placement may be asked to attend a summer session at Cornell or elsewhere in order to complete this work prior to matriculation at Cornell. Transfer candidates are encouraged to prevent such course deficiencies by consulting with the Transfer Admissions Committee as early as possible so that academic schedules may be planned to parallel Cornell's underclass program.

Students who are accepted for transfer on the basis of completion of two terms or three quarters of academic work with better-than-average records in other collegiate institutions generally will be awarded credit for thirty-three hours. However, there may be a stipulation that certain courses normally taken in the freshman year be completed as free electives before graduation. Similarly, above-average students who are accepted on the basis of completion of four terms or six quarters in other institutions generally will be awarded credit for sixty-six hours, with the possible provision that certain underclass courses be completed as free electives before graduation. In the case of students who are accepted for transfer admission but have only average academic records, individualized course credit evaluations will be made. University policy prohibits the granting of transfer credit for any course for which the student received a grade below C−.

Since 1968, the College of Engineering has offered Junior and Community College Scholarships to United States citizens who are currently enrolled in community or junior colleges and have been accepted for transfer admission to the College. As with all financial assistance, the amount of these special scholarships varies with each individual, depending upon his demonstrated financial need. A Parents' Confidential Statement (PCS), available from the College Scholarship Service at Princeton, New Jersey, must accompany the scholarship application.

Students who apply for transfer from other four-year colleges and universities cannot be considered for financial aid until they have completed one term in residency at Cornell.

Applications for transfer admission for the fall term beginning in September are due not later than April 15. Candidates who wish to be considered for midyear transfer must make application by December 1.

International Students

The College of Engineering encourages highly successful foreign students to consider the opportunities available at Cornell. Each year the College matriculates approximately thirty-five freshman students of foreign nationality. Students interested in admission to any Cornell division should communicate with the Undergraduate Admissions Adviser, International Student Office, Barnes Hall.

Special Students

In exceptional cases, individuals who do not wish to become candidates for an undergraduate degree may be admitted as special students. Persons who cannot meet the usual entrance requirements or who do not wish to spend the time required to complete a degree may qualify, but they must have had some engineering training and must satisfy the prerequisites for the courses they wish to take. Other applicants may have baccalaureate degrees but wish to pursue further work at the undergraduate level. In any case, a prospective special student should write to the director of the division or school to which he or she wants to be admitted.

Graduate Admission

Candidates may apply for admission to graduate programs in engineering leading to the general degrees of Master of Science and Doctor of Philosophy or to one of eleven professional Master of Engineering degrees. Admission requirements are discussed on pp. 13 and 14.

Finances

Expenses

Estimated expenses for an undergraduate student in the College of Engineering for the 1975–76 academic year total $6,300, which includes $3,800 for tuition and fees, an estimated $1,750 for room and board, $700 for personal expenses, and the $50 registration fee.

Additional details concerning these expenses, method of payment, refunds, and other matters of financial interest are given in the *Announcement of General Information*.

Undergraduate Financial Aid

Substantial aid is available to help students meet the cost of their education, and more than 70 percent of all undergraduate engineering students receive such aid. The College follows a policy of full-need awards: *financial aid is offered only if a package of scholarship, loan, and occasionally a job can be provided* to equal the calculated need. The total package for an individual may be as high as $6000 a year.

Freshman Applicants

More than $600,000 in scholarship grants will be awarded this year to College of Engineering freshmen. Loans and University jobs will increase the total amount of financial aid for engineering freshmen to about $800,000. Awards made to freshmen are normally continued through four years, contingent on continuance of the calculated need and satisfactory academic standing.

Freshmen seeking financial aid should complete the financial aid application form and file it, still attached to the admissions application, with the University Office of Admissions. The Parents' Confidential Statement of the College Scholarship Service must also be filed. Each applicant files only one application and should not request any specific scholarship. The Engineering Scholarship Committee attempts to assign specifically designated awards to those students whose qualifications most nearly match the donor's wishes.

No student should refrain from applying for admission because of financial circumstances. Admissions decisions are rendered without regard for financial aid requirements; after admission has been granted, applicants for financial aid are considered for the available funds.

Upperclassmen

For upperclassmen who *did not* receive aid as incoming freshmen, there are extremely limited sources of financial aid. The appropriate application forms may be obtained from the University Office of Scholarships and Financial Aid.

Transfer Students

During the past four years, the College of Engineering has enrolled increasing numbers of transfer students from junior and community colleges and has made the transition to Cornell financially possible by means of special Community and Junior College Scholarships. The availability of these funds makes Cornell, a private institution, as economically feasible as most publicly supported engineering schools.

In the past few years, all accepted two-year college transfer candidates of United States citizenship have been awarded financial aid commensurate with need as demonstrated by the student's financial aid application. Junior and community college students interested in Cornell engineering and this special scholarship program are invited to communicate with

the Chairperson, Transfer Admissions Committee, 221 Carpenter Hall.

Scholarship Resources

The total resources available for financial aid to undergraduate engineering students amount to about $1.75 million a year.

The largest single source of assistance is the John McMullen Scholarship Fund, which provides support for more than five hundred undergraduates every year. Total expenditures for these scholarships exceed $1 million annually.

A number of other scholarships and endowments have been established, often as memorials, to provide financial aid funds for Cornell engineering students. These scholarships carry the following names: Charles R. Armington, John Henry Barr, Seymour L. Baum, Robert H. Blackall, Edward P. Burrell, Russell Craig Chandler, Redmond Stephen Colnon, Casper L. Cottrell, Calvin H. and Della N. Crouch, A. Clinton Decker, Warren V. Delano, Otto M. Eiditz, Joseph H. Evans, C. Harold Fahy, Elbert Curtiss Fisher, Carl R. Gilbert, Emmet Blakeney Gleason, Paul G. Haviland, Hayward Headden, Howard Elmer Hyde, Martin J. Insull, Albert Jadot, Chester H. Loveland, Charles McAlister, Harrison D. McFaddin, Robert C. Newcomb, Frank William Padgham, Annie F. and Oscar W. Rhodes, Huldah Jane Rice, Frederick B. Scott, Sylvester Edick Shaw, Judson N. Smith, William Delmore Thompson, Leon C. Welch, Marthur Mellon Wellington, John L. Wentz, Henry G. White and Jessel Stuart Whyte. The Carrier Memorial Scholarship and the Wilson Endowment also provide funds.

Corporation-sponsored scholarship funds are the following: Alcoa Foundation, Moog, Inc., Niagara Machine and Tool Works, Rohm & Haas Company, Scott Paper Company Foundation, Stauffer Chemical Company, Western Electric Fund, and Wyman-Gordon Company. The *Cornell Engineer*, a student magazine, also provides scholarship funds.

Within the past few years, several corporations have helped support efforts to provide financial aid for minority students. These corporations are: Babcock and Wilcox Company, Continental Can Company, Corning Glass Works, E. I. duPont de Nemours & Company, Eastman Kodak Company, General Electric Company, S. C. Johnson Company, Mobil Oil Corporation, Raytheon Company, and Smith, Kline and French Laboratories.

In addition to these special engineering scholarships, there are University-wide scholarships for which accepted engineering applicants are eligible. These include the Cornell National Scholarships and the General Motors Scholarships.

Graduate Financial Aid

Opportunities for financial aid at the graduate level are discussed under Master of Engineering degree (see p. 13) and Master of Science and Doctor of Philosophy degrees (see p. 14).

Academic Standing

Grades

The faculty grades on a letter scale (A through F), refined by the use of + or −. In order to compute averages, grade points are assigned as follows:

A+ = 4.3	A = 4.0	A− = 3.7
B+ = 3.3	B = 3.0	B− = 2.7
C+ = 2.3	C = 2.0	C− = 1.7
D+ = 1.3	D = 1.0	D− = 0.7

No grade points are given for failing (F) grades. Grades which are sometimes given but not counted in computing grade-point averages are Satisfactory (S), Unsatisfactory (U), and Incomplete (Inc.).

Occasionally, students who are doing satisfactory work in a course may not be able to complete the work of the course because of unforeseen circumstances such as illness. In such instances, the professor may assign the grade Inc. Engineering students must make up grades of Incomplete by the end of the next term in which the course is given.

In any term after the first semester of freshman residence, an undergraduate may take one or two liberal or free elective courses on an S-U grading basis upon approval of the student's faculty adviser and the course instructor. The S-U option enables engineering students to take advanced courses or courses primarily for those majoring in other areas without affecting their grade-point averages.

Evaluation and Academic Action

The academic standing of each student is evaluated at the end of each semester. To be considered in good standing for the semester, a student in the Division of Basic Studies must successfully complete at least twelve credit hours, receive no grade of F or U, and attain the required minimum grade-point average. The minimum acceptable first and second semester grade-point average is 1.7; for the third, fourth, and any additional semesters in the Division of Basic Studies, the minimum is 2.0.

A student who is not in good standing or is not making adequate progress toward the degree will receive an official warning, will be suspended, or will be prohibited from further registration in the College. An official warning is notice that academic performance is not satisfactory, and that failure to attain good standing the following semester may result in suspension. Except in unusual cases, a first semester freshman not in good standing will be warned. A suspended student must present evidence that he or she can successfully complete an academic program in the College of Engineering to be considered for readmission.

Honors

Honors sections are available in a number of freshman and sophomore courses. Entrance to these sections is based on the quality of work in the preceding term.

To attain the Dean's Honor List for any term in the College of Engineering, an undergraduate must have attained a term average of at least 3.25, based on at least twelve credit hours in which grades other than S and U have been awarded.

To graduate with Distinction a student must have a 3.25 cumulative average for all undergraduate courses at Cornell.

Advanced Placement

It is possible for students to obtain academic credit toward the undergraduate degree by taking special high school courses or by achieving sufficiently high scores on special examinations. Details of the advanced placement program as it pertains to entering freshmen are given on p. 15.

Earning advanced credit allows a student to develop a more individualized program of study with a broader liberal component or additional technical courses; it is not normally used to reduce the academic program of any term.

Another possibility available to superior students is to complete a program leading to the B.S. degree in less time than the usual four years or eight terms through a combination of advanced placement credit and summer study. Studnts who gain advanced placement credit for two terms of mathematics and for chemistry or physics stand a good chance of shortening the time required for graduation.

Prospective students who are interested in advanced placement are invited to correspond with the Chairperson, Engineering Admissions Committee, 223 Carpenter Hall. Entering students should consult the Division of Basic Studies, 170 Olin Hall. Students already enrolled should consult their advisers.

Student Personnel Services

Advising and Counseling

The College of Engineering advising services are designed primarily to provide students with information and counseling in areas that affect their academic and professional development.

Advice on curricular choices and career planning is provided mainly through the faculty adviser, who helps each advisee plan an educational program and is responsible for overseeing the student's academic progress. The faculty adviser also serves as a personal counselor who will direct the student to the appropriate University resource when a particular need arises. Faculty advisers are assigned to matriculating students on the basis of indicated mutual interests; underclass students may change advisers if their interests change. Upperclass students are normally served by faculty advisers in their area of specialization. It is essential that students make full use of this important resource on a regular basis.

The College operates the Engineering Advising and Counseling Center in Olin Hall, where students may consult with the director of advising and counseling or with student staff members representing each of the upperclass fields. These students are particularly helpful in providing underclass students with peer counseling on the nature of the work in various fields. Special programs to assist students in selecting their upperclass field are offered by the Center at various times during the year.

A list of tutors is available at the Center, and group tutorials are arranged by the staff as the need arises. The student staff members will help individual students with short-term tutoring assistance while they are on duty in the Center. Also available at the Center is a wide variety of printed material, including publications of the College of Engineering. A monthly bulletin, *News Briefs*, containing information on various academic activities and programs, is distributed by the Center to all freshman and sophomore engineering students.

Special counseling services for minority-group students are available through the Director of Engineering Minority Programs, Carpenter Hall.

The University provides extensive resources to supplement the advising programs of the colleges. Facilities available to all students include the Office of the Dean of Students; the University Health Service; the Reading-Study Center; the University Guidance and Testing Center; the Office for Coordination of Religious Affairs; the Career, Summer Plans, and Placement Center; and the Office of Scholarships and Financial Aid.

Engineering students not only have access to these organized counseling services of the College and University, but are also welcome to confer with the administrative staff of the College of Engineering, department chairpersons, and faculty members on any educational or personal matter.

Placement

The facilities of the University Career, Summer Plans, and Placement Center in Sage Hall are available to all engineering students seeking summer or permanent employment. The College of Engineering also provides placement service through its Office of Student Placement in Carpenter Hall. Information about companies is available at either of these offices, and students may discuss specific employment opportunities and the procedures of job placement with the staff of either office.

The Office of Student Placement, in cooperation with the University's placement services, arranges annual interviews between students and prospective employers. Selected engineering faculty members serve as placement advisers with whom students may discuss their career objectives and plans for employment or graduate study.

Division of Basic Studies

Olin Hall

M. S. Burton, director; G. D. Meixel, Jr., assistant director; N.Langrana.

Students in the College of Engineering are enrolled for the first two years of their undergraduate education in the Division of Basic Studies, which administers the program of courses for freshmen and sophomores.

Course Requirements

Students are enrolled for five courses each term. Many of these are elective, but the underclass program must be planned so as to satisfy certain requirements. A sequence of four courses in mathematics and a three-term sequence in physics are required of all undergraduates. Freshmen enroll in chemistry during the first term and should elect a second term of chemistry if they plan a chemistry-related upperclass program.

A two-term sequence in engineering subjects, IBE105 and IBE106, is required of freshmen. Included is instruction in the computer language PL/I and an introduction to engineering design and graphics. Also, each student chooses two six-week "mini courses" which focus on different engineering fields and include a variety of activities, such as design or laboratory projects, field trips, discussion groups, and case studies of engineering-related problems and issues. Students interested particularly in bioengineering or premedicine may substitute a biology course for IBE106.

All engineering students are required to complete eight liberal studies courses (twenty-four credits) before graduation; four of these courses (twelve credits) are normally completed while the student is registered in the Division of Basic Studies. However, students whose career goals require them to do so, may substitute introductory courses in the natural sciences (e.g., biology or organic chemistry) for their liberal studies electives during the freshman or sophomore year, and defer these electives until the junior and senior years. The liberal studies electives may include courses in the humanities, social sciences, modern foreign languages, and expressive arts. At least two of the liberal studies elective courses (six credits minimum) must be at the upper class level.

All undergraduate students are required by the University to complete four terms of physical education. The requirement must be completed within the first four terms unless postponement is granted by the faculty committee on Physical Education. Requests for postponement should be made to the engineering registrar, 170 Olin Hall.

Descriptions of the physical education courses offered will be made available to entering students by the Department of Physical Education and Athletics.

During the sophomore year students take four engineering core science courses, selected from offerings in four areas, as outlined below. Students who are planning to major in chemical engineering as upperclass students must satisfy special prerequisites (see footnotes * below). A wise selection of core courses is of considerable importance to the student's subsequent program of studies and should be made in consultation with a faculty adviser.

The Curriculum

Typical programs for the freshman and sophomore years are given as examples. It should be noted that there are many variations, depending on students' individual backgrounds and educational and career plans.

Freshman and Sophomore Years

Term 1	*Credits*
Mathematics 191, Calculus for Engineers	4
Chemistry 207, General Chemistry	3
Freshman engineering course, IBE105 or IBE106	3
Natural or social science elective*	3
Liberal studies elective	3
Term 2	
Mathematics 192 or 194, Calculus for Engineers	4
Physics 112, Physics I	4
Freshman engineering course IBE105 or IBE106 or alternative†	3
Natural or social science elective*	3
Liberal studies elective	3
Term 3	
Mathematics 293 or 295, Engineering Mathematics	4
Physics 213, Physics II	4
Engineering core science elective	3
Engineering core science elective	3
Liberal studies elective	3
Term 4	
Mathematics 294 or 296, Engineering Mathematics	3
Physics 214, Physics III	4
Engineering core science elective	3
Engineering core science elective	3
Liberal studies elective	3

*Students who wish to major in chemical engineering and students who are interested primarily in bioengineering-premedicine must take Chemistry 208 during the freshman year. Chemical engineering students will select a considerably different program in the sophomore year (see footnote * under Engineering Core Sciences).

†Students interested primarily in bioengineering or bioengineering-premedicine may substitute Biological Science 102 plus 104 (laboratory) for IBE 106 (see p. 32).

Engineering Core Sciences

Four engineering core science courses must be taken during the sophomore year. Each student selects courses from the four groups listed below, with at least three of the four groups represented in the choices.

An important consideration in the choice of these courses is that each upperclass field is entitled to specify a particular engineering core science as a prerequisite for enrollment in the junior year. The courses required for entry into the different Field Programs are the following:

Applied and Engineering Physics: IMG221
Chemical Engineering: IHE111 or IHE110*
Civil and Environmental Engineering: IAK221
Electrical Engineering: IEE210
Industrial Engineering and Operations Research: IOR260
Materials Science and Engineering: no requirement
Mechanical and Aerospace Engineering: IAK221

*Students intending to enter Chemical Engineering must also take Chemistry 287, 289, and Chemistry 288, 290. Only two of the Group IV courses may be counted toward the four engineering core sciences required of all sophomores. Students who take the three courses from Group IV during the sophomore year may be unable to complete the engineering core science requirements that year, and may defer the fourth engineering core science until the junior year.

The four groups of engineering core sciences are:

Group I	*Credits*
IOR213, Systems Analysis and Design	3
IOR260, Introductory Engineering Probability	3
IOR270, Basic Engineering Statistics	3
ICS211, Computers and Programming	3
Group II	
IEE210, Introduction to Electrical Systems	3
ITE262, Electrical Properties of Materials	3
IP217, Contemporary Topics in Applied Physics	3
IP306, The Physics of Life	3
Group III	
IAK201, Introduction to Applied Mechanics	3
IAK221, Mechanics of Solids	3
IAK231, Dynamics	3
ITE261, Mechanical Properties of Materials	3
Group IV	
Chemistry 287, 289, Physical Chemistry	5
Chemistry 288, 290, Physical Chemistry	5
Chemistry 357, Organic Chemistry	3
Chemistry 358, Organic Chemistry	3
IMG221, Thermodynamics	3
IHE111 or IHE110, Mass and Energy Balances	3

Description of Courses

The courses offered through the Division of Basic Studies include certain engineering courses offered by the various schools and departments of the College of Engineering, and a number in mathematics and the physical sciences which are offered by the College of Arts and Sciences but are required or frequently included in the underclass engineering curriculum. These courses are described below. Other courses offered by schools or departments of the College of Engineering are described in a later section of this book. The significance of the course numbering system is discussed on p. 67.

IBE100 Bioengineering Seminar Either term. Credit one hour. S-U grades only. N. Langrana and staff.
Lectures by Cornell staff members, graduate students, and visiting scientists and engineers on topics of interest in the field of bioengineering.

IBE103 Special Investigations in Engineering On demand. Credit variable.
Supervised study, by individuals or small groups, of one or more specialized topics not covered in regular courses.

IBE105 Elements of Engineering Communications Either term. Credit three hours. Two lectures. No scheduled recitation or laboratory, but optional recitation offered. N. Langrana and staff.
First eight weeks same as ICS100. Remaining weeks, principles of engineering graphics studied through projects related to design and modeling of physical processes. Emphasis on sketching to develop skill in visual communication.

IBE106 Engineering Perspectives Either term. Credit three hours. One lecture, one recitation, one laboratory.
Illustration of engineering point of view through detailed study of specific problems with major engineering aspects. Students choose "mini-courses" from selection offered by various faculty members in the College of Engineering. Small recitations and work sessions permit close contact between students and faculty. Lectures present an overview of the engineering profession.

Mathematics

191 Calculus for Engineers Either term. Credit four hours. Three lectures plus recitations. Prerequisite: three years of high school mathematics, including trigonometry.
Plane analytic geometry, differential and integral calculus, applications.

192 Calculus for Engineers Either term. Credit four hours. Three lectures plus recitations; evening examinations. Prerequisite: Mathematics 191.
Transcendental functions, technique of integration and multiple integrals, vector calculus, analytic geometry in space, partial differentiation, applications.

194 Calculus for Engineers Spring. Credit four hours. Three lectures plus recitations; evening examinations. Prerequisite: recommendation of instructor in 191.
Covers the course content of 192 in more detail and includes more theoretical material.

293 Engineering Mathematics Either term. Credit four hours. Three lectures plus recitations; evening examinations. Prerequisite: Mathematics 192 or 194.
Vectors and matrices, first order differential equations, infinite series, complex numbers, applications. Problems for programming and running on the automatic computer are assigned, and students are expected to have a knowledge of computer programming equiavalent to that taught in IBE105.

294 Engineering Mathematics Either term. Credit three hours. Two lectures plus recitations; evening examinations. Prerequisite: Mathematics 293.
Linear differential equations, quadratic forms and eigenvalues, differential vector calculus, applications.

295 Engineering Mathematics An honors section of 293. Fall. Credit four hours. Three lectures plus recitations; evening examinations. Prerequisite: Mathematics 192 or 194.
Lectures follow the general plan and cover the material of 293 with substantially greater emphasis on fundamental unifying concepts. Additional topics may include: an introduction to convergence in metric spaces, the role of complex numbers in clarifying the behavior of real power series and real linear transformation, invariant subspaces of a linear transformation, and the Jordan canonical form.

296 Engineering Mathematics An honors section of 294. Spring. Credit four hours. Three lectures plus recitations; evening examinations. Prerequisite: Mathematics 295 or consent of instructor.
Lectures follow the general plan and cover the material of 294 with substantially greater emphasis on fundamental unifying concepts. Additional topics may include: a development of the theory of linear ordinary differential equations with constant coefficients via the matrix exponential function, fundamental solution matrices for time-dependent linear ordinary differential equations, particular solutions via the superposition integral. Recitation work includes one major problem-solving project involving modeling, computer programming, and, possibly, experimental verification.

Physics

112 Physics I: Mechanics and Heat Either term. (Usually offered also during Summer Session.) Credit four hours. Two lectures, two discussion periods; one two-hour laboratory in alternate weeks; evening examinations. Prerequisite: coregistration in Mathematics 192; or substantial previous contact with introductory calculus combined with coregistration in Mathematics 191. K. Berkelman (fall), R. Siemann (spring).
Mechanics of particles: kinematics, dynamics, special relativity, conservation laws, central force fields, periodic motion. Mechanics of many-particle systems: center of mass, rotational mechanics of a rigid body, static equilibrium, kinetic theory, and thermodynamics of simple gases. At the level of *Fundamentals of Physics* (revised printing, 1974) by Halliday and Resnick.

213 Physics II: Electricity and Magnetism Either term. (Usually offered also during Summer Session.) Credit four hours. Two lectures, two discussion periods, laboratory; evening examinations. Prerequisites: Physics 112 and coregistration in the continuation of the mathematics sequence required for Physics 112. J. Silcox (fall), R. Buhrman (spring).
Electrostatics, behavior of matter in electric fields, magnetic fields, Faraday's Law, electromagnetic oscillations and waves, magnetism. Laboratory work supplements the written and oral work: electrical measurements, dc and ac circuits, resonance phenomena, physical electronics, electrical conduction, selected properties of electric and magnetic fields. At the level of *Fundamentals of Physics* (revised printing, 1974) by Halliday and Resnick.

214 Physics III: Optics, Waves, and Particles Either term. (Usually offered also during Summer Session.) Credit four hours. (Physics 310 may be taken, with consent of instructor, in place of the 214 laboratory; credit for 214 is then three hours.) Two lectures, discussion periods, laboratory; evening examinations. Prerequisites: Physics 213 and coregistration in the continuation of the mathematics sequence required for Physics 112.
Wave phenomena; electromagnetic waves; physical optics; quantum effects, matter waves; uncertainty principle; introduction to wave mechanics, elementary applications. At the level of *Fundamentals of Optics and Modern Physics* by Young (final selection of text to be announced).

217 Physics II: Electriciy and Magnetism Either term. Credit four hours. A more rigorous version of Physics 213 for students who have done very well in Physcis 112 and desire a more analytic treatment than that of 213. Acceptance into the course will be determined by the instructor. Engineering students should seek the approval of their adviser before registering. Physics majors are encouraged to select 217. Students are required to do the laboratory work offered in 213 to obtain credit for 217. Evening examinations may be scheduled. A. Sievers (fall), L. Hand (spring).
Fundamentals of electricity and magnetism, including the use of vector calculus. At the level of *Electricity and Magnetism* by Purcell (Vol. II, Berkeley Physics Series).

218 Physics III: Optics, Waves, and Particles Either term. Credit three hours. A special section of 214. Conditions governing enrollment are similar to those for 217. Students are required to do the laboratory work offered in 214 (for which one credit hour will be given) or to enroll concurrently in 310. Evening examinations may be scheduled. T. M. Yan (fall), R. Pohl (spring).

Chemistry

207–208 General Chemistry Fall: 207; credit three hours. Spring : 208; credit four hours. Two lectures, one laboratory; evening examinations. Enrollment limited. Recommended for those students who will take further courses in chemistry. Prerequisite: high school chemistry; 207 is prerequisite to 208. (Note: Entering students exceptionally well prepared in chemistry may receive advanced placement credit for 207–208 by demonstrating competence in the Advanced Placement Examination of the College Entrance Examination Board, or in the departmental examination given at Cornell before classes start in the fall.) F. R. Scholer and E. L. Muetterties (fall), M. J. Sienko (spring).
The important chemical principles and facts, with emphasis on quantitative aspects and techniques important for further work in chemistry. Second-term laboratory includes a systematic study of quantitative analysis.

Engineering Sciences

Group I

IOR213 Systems Analysis and design Spring. Credit three hours. Two lectures, one recitation. Prerequisite: Mathematics 293. T. Berger.
Introduction to the modeling of systems using the concepts of states and transitions. Emphasis on the formulation of models common to problems in various branches of engineering. Use of graph theory, difference equations, and Markov chains to analyze and design static and dynamic systems.

IOR260 Introductory Engineering Probability Either term. Credit three hours. Three lectures. Prerequisite: First year calculus. L. I. Weiss and staff.
At the end of this course a student should have a working knowledge of some of the basic tools in probability theory and their use in engineering. This may be the last course in probability for some students or it may be followed by a course in statistics. Topics include: a definition of probability; basic rules for calculating with probabilities when the number of possible outcomes is finite; discrete and continuous random variables; probability distribution and density functions; expected values, jointly distributed random variables, and marginal and conditional distributions; special distributions important in engineering work, i.e., the normal, exponential, binomial, Poisson, and other distributions and how they arise in practice; and Markov chains and applications.

IOR270 Basic Engineering Statistics Either term. Credit three hours. Two lectures, one recitation. (Graduate students will be assigned to a separate recitation section.) Students who intend to enter the upperclass Field of Industrial Engineering and Operations Research should take IOA260 instead of this course. Prerequisite: first year calculus. Staff.
At the end of this course a student should command a working knowledge of basic statistics as it applies to engineering work. For many students this will be the only course in statistics they take. For students who wish to learn more about statistics, a course in probability (e.g., IOA260) followed by a course in statistics (e.g., IOC370) is recommended. Topics are: graphical and numerical methods of representing data—histograms and cumulative frequency polygons, sample means and variances; basic tools of probability, discrete and continuous random variables, probability distribution and density functions, expected values and "population" moments, special distributions—the normal, chi-square, binomial, and others; tests of "significance" and one- and two-sided hypothesis tests concerning the mean of a normal distribution when the standard deviation is known (unknown); hypothesis tests concerning the variance of a normal distribution; point- and confidence-interval estimation; correlation and curve fitting by least squares.

ICS211 Computers and Programming Either term. Credit three hours. Prerequisite: ICS100 or equivalent programming experience. Two lectures, one two-hour laboratory.
Intended as a foundations course in computer programming. Algorithms and their relation to computers and programs. Analysis of algorithms in terms of space and time requirements. A procedure-oriented language; specification of syntax and semantics, data types and structures, statement types, input-output program structure. A brief introduction to machine organization. Programming and debugging problems on a computer are an essential part of this course.

Group II

IEE210 Introduction to Electrical Systems Either term. Credit three hours. Three lecture-recitations. Prerequisites: Mathematics 192 and Physics 112.
Intended to develop competence in several analysis skills appropriate to the Field of Electrical Engineering and to impart understanding of the physical basis for the concepts associated with the skills. Topics include: electrical circuit elements (resistors, capacitors, inductors, independent sources, and branch relationships); time functions and their representation (real exponentials, complex numbers, trigonometric functions, and complex exponentials); response of simple networks and the impedance concept (natural response, forced response to periodic excitation and pole-zero concepts); circuit equations and methods of solution (branch equations, Kirchhoff's laws, nodal and mesh equations, matrix methods of solution, and Norton and Thevenin equivalents); controlled sources and modeling of devices (representation of idealized electronic and electromechanical devices).

ITE262 Introduction to Electrical Properties of Materials Spring. Credit three hours. Two lectures, one recitation or laboratory.
Electronic structure of atoms, molecules, and crystal-

line solids. Electrical conductivity and other electrical properties of metals, semiconductors, and insulators. Semiconductors and their applications in electronic devices. Magnetism and magnetic materials. Introduction to lasers.

IP217 Contemporary Topics in Applied Physics Spring. Credit three hours. Two lectures, recitation-laboratory. Prerequisite: Physics 213. V. O. Kostroun and staff.
Selected examples of contemporary applications of modern physics. The objective is to develop a semiquantitative understanding of the underlying physical principles and phenomena and the intrinsic limits they place on applications. The interplay between physics and other factors (technological, scientific, and, when relevant, social) that set limits on application of modern physics and influence its development. For example, nuclear energy utilization may be studied in terms of the physics of fission, fusion, and plasmas, along with the technological and social factors affecting development of nuclear energy sources. Applications of physics in other sciences such as astrophysics and biology may also be studied.

IP306 The Physics of Life Spring. Credit three hours. Two lectures. Prerequisite: Physics 213 or consent of instructor. A. Lewis.
The physics of life within the unity and interdependence of living matter. A foundations course in biophysics and bioengineering, or an introduction to the physical basis of life for students specializing in other engineering disciplines or in physics. Focus is on photosynthesis and the underlying molecular physics. The two products of photosynthesis, oxygen and starch, and their functions in the body. Hemoglobin protein structure and function. Various forms of the transport equation. The physical basis of membrane structure and function. The utility of oxygen and starch in animals and the crucial function of the membrane in this biological interdependence. Reproduction and the critical role of nucleic acids. An introduction to statistical mechanical approaches to nucleic acid function. Perception by the organism.

Group III

IAK201 Introduction to Applied Mechanics Either term. Credit three hours. Two lectures, one recitation a week; four laboratory sessions per term. Prerequisite: registration in Mathematics 293. Students may not receive credit for both IAK201 and IAK221, or for both IAK201 and IAK231.
An integrated treatment of the mechanics of solids and fluids for students in engineering, life sciences, and interdisciplinary programs. Consists of an introduction to the fundamental concepts of statics, dynamics, continuum mechanics, and the properties of materials, with application of these concepts in discussions of several practical examples drawn from solid and fluid mechanics. These include the torsion, bending, and buckling of structural members, time-dependent and statical problems in elasticity and fluids at rest, perfect fluids, and fluids with friction.

IAK221 Mechanics of Solids Either term. Credit three hours. Two lectures, one recitation; laboratory participation four times per term. Prerequisite: registration in Mathematics 293.
Principles of statics, force systems, and equilibrium. Mechanics of deformable solids, stress, strain, statically determinate and indeterminate problems. Properties of engineering materials. Analysis of slender bars, shearing force, bending moment, singularity functions. Plane stress, transformation of stress, Mohr's circle of stress and strain. Bending and torsion of slender bars: stresses, deformations, and plastic behavior.

IAK231 Dynamics Either term. Credit three hours. Two lectures, one recitation; laboratory participation four times per term. Prerequisite: registration in Mathematics 294.
Principles of Newtonian dynamics of a particle, systems of particles, and a rigid body. Kinematics, frames of reference, motion relative to a moving frame, impulse, momentum, energy. Laws of motion of a system, center of mass, total kinetic energy, moment of momentum, constraints. Rigid body kinematics, angular velocity, moment of momentum and the inertia tensor, Euler equations, the gyroscope. Advanced methods in dynamics. As time permits: generalized coordinates, Lagrange's equations, the potential energy function, the kinetic energy function, applications. At the level of *Applied Mechanics-Dynamics* by Housner and Hudson.

ITE261 Introduction to Mechanical Properties of Materials Either term. Credit three hours. Two lectures, one recitation or Laboratory.
The relation of mechanical properties, such as strength in tension, to microscopic structures and defects inside metals and other materials. Deformation of rubber-like polymers. Permanent changes in the shape of crystals caused by the action of stresses. The effect that the movement of atoms has on the strength of solids at high temperatures. Manipulation of the microscopic structures of materials to produce high strength; specific practical examples, such as the strengthening of steel. How materials fail by fracture and from fatigue. Instruction materials include short movies, slides, and programmed instruction booklets. Laboratory work includes testing of the mechanical properties of metal alloys and rubber, and microscopic examination of the structure of some typical materials.

Group IV

Several courses in physical and organic chemistry offered by the Department of Chemistry in the College of Arts and Sciences qualify as engineering core sciences.

287–288 Introductory Physical Chemistry Fall: 287; spring: 288. Credit three hours per term. Two or occasionally three lectures, one recitation; evening examinations may be scheduled. Prerequisites: Chemistry 208 or 216 and Mathematics 191–192. B. Widom (fall), A. C. Albrecht (spring).
A systematic treatment of the fundamental principles of physical chemistry.

289–290 Introductory Physical Chemistry Laboratory Fall: 289; spring: 290. Credit two hours per term. One evening lecture, two laboratories including some Chemistry 287–288 recitation. Prerequisite: 289 is prerequisite to 290; coregistration in Chemistry 287–288 is required.
The development of needed skills in the experimental aspects concerned with the fundamental principles of physical chemistry.

357–358 Introductory Organic Chemistry Fall: 357; spring: 358. Credit three hours per term. Three lectures; optional recitations may be offered; evening examinations may be scheduled. Prerequisite: Chemistry 208 or 216; Chemistry 357 is prerequisite to 358. J. Meinwald.
A systematic study of the more important classes of carbon compounds, reactions of their functional groups, methods of synthesis, relations, and uses.

IMG221 Thermodynamics Either term. Credit three hours. Three recitations. Prerequisites: Mathematics 191 and 192 and Physics 112.
The definitions, concepts, and laws of thermodynamics. Applications to ideal and real gases, multiphase pure substances, gaseous mixtures, and gaseous reactions. Heat-engine and heat-pump cycles. An introduction to statistical thermodynamics.

IHE110 Mass and Energy Balances Either term. Credit three hours. Prerequisite: one year of freshman chemistry or consent of instructor. R. G. Thorpe.
Content is the same as for IHE111, but this course uses *only self-paced audiovisual instruction at the convenience of the student*. A minimum of seventy clock hours of audiovisual instruction is required to master the subject matter. Student performance is evaluated by nine tests, two preliminary examinations, and a final examination. Superior students may earn exemption from the final examination.

Areas of Instruction

The program of the Division of Basic Studies, in which all freshmen and sophomores are enrolled, is described in the preceding section. More specialized areas of instruction, mainly for upper-division and graduate students, are described here.

Aerospace Engineering

See p. 55.

Agricultural Engineering

Riley-Robb Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Agricultural). Master of Science, Doctor of Philosophy.

E. S. Shepardson, director; R. D. Black, J. R. Cooke, R. B. Furry, W. W. Gunkel, D. A. Haith, L. H. Irwin, W. J. Jewell, G. Levine, R. C. Loehr, H. A. Longhouse, R. T. Lorenzen, D. C. Ludington, W. F. Millier, G. E. Rehkugler, N. R. Scott, J. W. Spencer.

Courses of instruction are listed on pp. 68–70. A complete description of the courses in agriculture may be found in the *Announcement of the College of Agriculture and Life Sciences*.

A joint program in agricultural engineering, administered by the College of Agriculture and Life Sciences and the College of Engineering, leads to the degree of Bachelor of Science. Students are registered in the College of Agriculture and Life Sciences for the first three years and in the College of Engineering for the fourth year. The degree is awarded by the College of Engineering. During the first two years, the student follows the Basic Studies Program with a few exceptios, and during the last two years, follows a College Program.

The purpose of this curriculum is to prepare engineers for careers in the many industries and agencies that supply the great variety of products, machines, and services required for commercial agriculture, or that process, handle, and distribute agricultural products. More specialized study is offered in the various graduate degree programs.

Laboratory and Research Facilities

Riley-Robb Hall, on the campus of the College of Agriculture and Life Sciences, provides excellent classroom and laboratory facilities for both teaching and research. Major items of laboratory equipment include electric dynamometers, universal testing machines, fluid flow demonstration and metering equipment, strain measurement instruments, digital recording equipment, an electronic analog computer, torque meters, high-speed camera and film analysis equipment, modern farm machines, power units and materials-handling equipment, soil properties and moisture determination apparatus, and complete machine shop facilities.

Laboratory equipment and space in Riley-Robb Hall permit investigation of many aspects of agricultural waste management, including liquid and solid waste handling, treatment and disposal, and odor control. A separate waste treatment laboratory is used for waste management pilot plant studies.

The Department has an extensive research program supported through the Cornell Agricultural Experiment Station. This also serves to provide many students with opportunities for part-time work during the academic year and for summer employment.

The Degree Programs

Bachelor of Science

A curriculum for the underclass years is given below.

Term 1	*Credits*
Mathematics 191, Calculus for Engineers	4
Chemistry 103 or 207	3
Agricultural Engineering 151, Introduction to Agricultural Engineering Measurements and Graphics	3
Biological Sciences 101 and 103	4
or 109	3

Liberal Studies elective (freshman seminar)	3
Term 2	
Mathematics 192, Calculus for Engineers	4
Physics 112, Physics I	4
Agricultural Engineering 152, Engineering Measurements and Graphics	3
Biological Sciences 102 and 104	4
or 110	3
Liberal studies elective (freshman seminar)	3
Term 3	
Mathematics 193, Engineering Mathematics	4
Physics 213, Physics II	4
Engineering core science	3
Engineering core science	3
Liberal studies elective	3
Term 4	
Mathematics 294, Engineering Mathematics	4
Physics 214, Physics III	4
Engineering core science	3
Engineering core science	3
Liberal studies elective	3

In addition to these courses, all freshmen and sophomores must satisfy the University's requirements in physical education.

The curriculum for terms 5 through 8 must consist of:

1. Engineering: minimum of thirty credit hours

a. Agricultural engineering: minimum of twelve credit hours at the 450 level or higher

b. Engineering sciences

2. Biological sciences or agricultural electives: minimum of twelve credit hours

3. Liberal studies electives: minimum of twelve credit hours

4. Free electives: minimum of six credit hours

Appropriate summer work experience is encouraged, and faculty advisers will assist their advisees in obtaining suitable jobs.

To remain in good standing in Agricultural Engineering, a student must attain a weighted average of at least 2.0 each term.

Agricultural Engineering Minor (College Program). College Program students interested in the application of engineering to plant and animal systems may elect an agricultural engineering minor which has the following requirements: (1) a minimum of six hours of agricultural engineering courses at the 400 level or above; (2) a minimum of six hours of biological science and/or agriculture courses beyond the introductory biological science sequence; and (3) a minimum of six hours of engineering courses related to the student's interest in agricultural engineering. These courses are selected by the student in consultation with the faculty adviser for the minor.

Master of Engineering (Agricultural)

The degree of Master of Engineering (Agricultural) is available as a curriculum type of professional degree, intended primarily for those students who plan to enter engineering practice and not for those who expect to study for the doctorate. This program consists of courses which are intended to develop students' backgrounds in engineering design as well as to strengthen their fundamental engineering base. Six hours of the required thirty hours consist of engineering design experience involving individual effort and a formal report. Admission to the M.Eng. (Agricultural) program is open to persons who have been granted a bachelor's degree from an accredited engineering curriculum or the equivalent and who have sufficient training to indicate that they can profitably study the advanced courses offered in the program. A student may choose to concentrate in one of the subareas of agricultural engineering or take a broad program without specialization. The subareas are: *(a)* power and machinery, *(b)* soils and water engineering, *(c)* agricultural structures and associated systems, *(d)* electric power and processing, and *(e)* agricultural waste management.

Engineering electives are chosen from among subject areas relevant to agricultural engineering, such as thermal engineering, mechanical design and analysis, theoretical and applied mechanics, structural engineering, hydraulics, sanitary engineering, soil engineering, and waste management.

Master of Science and Doctor of Philosophy

Flexible programs leading to the Ph.D. degree are offered in the following areas of specialization: agricultural engineering, agricultural structures, power and machinery, soil and water engineering, electric power and processing, and agricultural waste management. Two minor subjects, at least one of which must be in an engineering, agricultural, or basic science subject outside the Field of Agricultural Engineering, are also selected. Candidates for the M.S. degree take agricultural engineering as their major subject and select one minor from outside the field.

A broad and active research program, supported by the Cornell Agricultural Experiment Station, gives graduate students an opportunity to select challenging research projects for their theses. Assistantships and traineeships are available, and provide annual stipends comparable to those offered at other land-grant institutions.

More detailed information, along with application forms and other descriptive information pertinent to M.S. and Ph.D. programs in this field, may be obtained by writing to the Office of the Graduate Faculty Representative (Agricultural Engineering), Riley-Robb Hall.

Applied and Engineering Physics

Clark Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Engineering Physics), Master of Science, Doctor of Philosophy.

B. W. Batterman, director; P. L. Hartman, associate director; R. A. Buhrman, K. B. Cady, D. D. Clark, R. K. Clayton, T. A. Cool, D. R. Corson, T. R. Cuykendall, H. H. Fleischmann, S. Humphries, V. O. Kostroun, J. A. Krumhansl, A. Kuckes, B. R. Kusse, A. Lewis, R. L. Liboff, R. V. Lovelace, M. S. Nelkin, E. L. Resler, Jr., T. N. Rhodin, M. M. Salpeter, B. M. Siegel, J. Silcox, R. N. Sudan, W. W. Webb, G. J. Wolga.

Courses of instruction are listed on pp. 71–74.

The solution of many significant problems in engineering and applied science requires a thorough knowledge of physics and applied mathematics, and the ability to apply this knowledge effectively. The degree programs of the School of Applied and Engineering Physics are designed to provide education in the basic sciences at an intellectually challenging level and to prepare the student for a wide range of possible specialization in later professional development. These programs are particularly suitable for students who are willing to defer the early study of specific applications in order to have a wider choice of problems on which they can later work with competence and sophistication.

Research and Laboratory Facilities

The School of Applied and Engineering Physics is centered in Clark Hall, which houses the University's physical sciences library; offices of the Department of Physics, the Materials Science Center, and the Program on Science, Technology, and Society; research laboratories and supporting services in solid state physics and materials science; and a computer terminal. Facilities of other University laboratories and centers also are available for research in applied and engineering physics; these include the Center for Radiophysics and Space Research, the Ward Laboratory of Nuclear Engineering, the Laboratory of Plasma Studies, and facilities of the Division of Biological Sciences and of other schools and departments in the College of Engineering.

The Degree Programs

Bachelor of Science

The Field Program in Engineering Physics is designed to develop proficiency in physics and applied mathematics with emphasis on those areas of greatest applicability to engineering and to other sciences. Its distinguishing feature is a focus on concepts of broad applicability presented in an intellectually demanding and challenging context. For the able student, it provides an opportunity to develop a general ability to solve difficult problems and to acquire experience in making specific applications. The flexibility of the program allows the student to choose areas of concentration within and outside of physics during the undergraduate years. Most students go on to graduate study in a wide variety of fields, and they find that the strength and flexibility of their undergraduate preparation makes them desirable candidates for admission to many different graduate and professional programs.

It is difficult to predict for freshmen the particular areas of engineering or applied science that will appear most exciting and offer the best career opportunities when they enter the job market. Certain general trends are clear, however. As more difficult questions are asked in a given field, there is greater need to go back to fundamental knowledge in order to find answers. Particular techniques of application become rapidly obsolete, but the underlying scientific base changes much more slowly. Also, subject areas become more specialized at advanced levels; many subjects that are highly exciting at the graduate level have no direct undergraduate counterparts or are better prepared for by study in basic science and mathematics than by specialized undergraduate work. Conversely, excitement in the study of physics is increasingly the result of its applications in other scientific areas and in engineering.

A unique opportunity is available for students to have direct contact with research programs in engineering physics. These are senior research projects which are taken for credit and involve work in an ongoing research project. Qualified students are eligible to enter into these programs as early as the second semester of the junior year.

Many undergraduates who pursue a major in engineering physics go on to graduate work in such fields as astrophysics, atmospheric sciences, biophysics, energy conversion, environmental science, geophysics, materials science and engineering, nuclear engineering, nuclear physics, oceanography, plasma physics, quantum optics, and solid state electronics. Since a proper preparation for many of these areas of study depends upon an appropriate choice of undergraduate electives, each student should discuss his or her program with an engineering physics faculty member as early as possible during the undergraduate years. Some currently active areas of study and the names of professors who have special interest in these areas are: *biophysics,* A. Lewis, W. W. Webb, and B. Siegel; *geophysics,* A. Kuckes; *materials science,* B. W. Batterman, J. Silcox, and T. N. Rhodin; *nuclear engineering,* D. Clark and K. B. Cady; *lasers and quantum electronics,* T. Cool and G. Wolga; *plasma physics,* H. Fleischmann, B. Kusse, R. Lovelace, and R. Sudan.

Another alternative for students who specialize in engineering physics as undergraduates is entry into a professional Master of Engineering program in engineering physics, nuclear engineering, or aerospace engineering. Further study in other professional fields for which a background in applied science is less directly applicable is also a possibility. Some baccalaureate graduates go directly to industrial positions that often entail on-the-job or advanced training programs.

The first two years of the undergraduate program are administered by the Division of Basic Studies. Students who are planning to enter the Field Program in Engineering Physics are encouraged to register in honors sections of physics and mathematics during these two years. Those who have advanced standing in mathematics when they matriculate in the College are advised of the possibility of taking Physics 112 in the fall term of the freshman year and Mathematics

421 in the spring term of the sophomore year. Of the core engineering sciences studied in the first two years, a course in thermodynamics (IMG221 or Physical Chemistry 287) is required. The courses IP217, Contemporary Topics in Applied Physics, and IP306, The Physics of Life, are strongly recommended for the sophomore year.

The following curriculum, or its equivalent, constitutes the upperclass Field Program.

Term 5	*Credits*
IP333, Classical Mechanics	4
IP355, Electricity and Magnetism	4
Applied Mathematics I*	4
Free elective	3 or 4
Liberal studies elective	3 or 4
Term 6	
IP461, Quantum Mechanics	4
IP456, Electrodynamics	4
Applied Mathematics II*	4
Electronic Circuits†	3 or 4
Liberal studies elective	3 or 4
Term 7	
IP323, Statistical Physics	4
Physics 410, Experimental Physics	4
Applied Mathematics III*	4
Technical elective	3 or 4
Liberal studies elective	3 or 4
Term 8	
IP434, Continuum Physics	4
Applications of Quantum Mechanics††	3 or 4
Free elective	3 or 4
Technical elective	3 or 4
Liberal studies elective	3 or 4

*Applied Mathematics I and II may be either Mathematics 421–422 or IAA680–681. Applied Mathematics III may be Mathematics 423, IAA682, or another mathematics course such as Mathematics 411, 427, 428, or 371. Alternate courses will be considered on petition.
†Electronic Circuits may be Physics 360 or an equivalent junior-level electronics course.
††A choice of the following courses may be made: Physics 454, Introductory Solid State Physics; Physics 444, Nuclear and High-Energy Particle Physics; IP609, Low-Energy Nuclear Physics (fall term); IP401, Physics of Atomic and Molecular Processes (fall term); IEE731, Quantum Electronics I (fall term).

The student is reminded that of the four upperclass liberal studies elective courses, two are to be at an advanced level. (see p. 9.)

Considerable flexibility is possible in the scheduling of these courses. For example, Physics 410 may be taken in term 7 or in term 8. Quantum mechanics can be studied in term 6 as IP461 or in term 7 as Physics 443. The course in applications of quantum mechanics can be taken whenever the appropriate prerequisite has been met. If scheduling conflicts arise, the School may allow substitutions of courses nearly equivalent to the listed required courses: Physics 325–326 and IEE313–314 are similar to IP355 and IP456; Physics 318 (offered in the spring) and IAC670 are similar to IP333; and one of a number of advanced courses in fluid mechanics or elasticity are similar to IP434.

Free and technical electives need not be all formal course work; as noted above, qualified students may undertake informal study under the direction of a member of the faculty. This may include research projects undertaken mostly during the senior year in areas in which faculty members are active. These areas include electron microscopy and diffraction, quantum electronics, solid state and surface physics, atomic physics, geophysics, biophysics, nuclear structure physics, nuclear engineering, and plasma physics.

The engineering physics student is expected to pass every course for which he or she is registered, to attain each term a grade-point average of at least 2.3, and to demonstrate aptitude and competence in the basic subject matter of the curriculum.

Areas of Concentration Through a judicious choice of electives in the first two years, a student who plans to enroll in engineering physics can develop a coherent supplementary program. This can be important in preparing for graduate work in many interdisciplinary fields. Four typical examples are the following:

1. *Biophysics.* A student interested in biophysics may choose electives in biology and chemistry to create a coherent biophysics major within the engineering physics curriculum. The student begins with the introductory biology courses, Biological Sciences 101–103 and 102–104, as natural science electives in the freshman year. (It should be noted, however, that a student with good preparation in high school biology may qualify, by taking the necessary placement examinations in the fall, for Biological Sciences 109, which offers introductory biology in one term.) A good selection of electives for the sophomore year would be IP306, The Physics of Life, taken in the spring term, and the organic chemistry sequence 253 in the fall term and either 301 (a four-hour course) or 251 (a two-hour course) in the spring term. During the junior year this student could elect Physical Chemistry 389–390. The senior-year requirement for a course in applications of quantum mechanics could be met by taking Physics 454, Applied and Engineering Physics IP401, Chemistry 794, or Chemistry 798. Finally, technical electives that would be appropriate for this student include the Applied and Engineering Physics courses IP601, IP603, IP605, and IP610; and Biological Sciences courses 313 (Histology), 410–411 (General Animal Physiology), 431 (Principles of Biochemistry), 321 (Neurobiology and Behavior), 425 (Vision), 280–281 (Human Genetics), and 386 (Animal Embryology).

2. *Geophysics.* A student interested in geophysics may choose geological sciences courses IGE101-102 or else IGE101 and Chemistry 208 as natural science electives in the freshman year. In the sophomore year an appropriate choice of engineering sciences would be IEE210, ITE261, IMG221, and IP217. In the junior year the geological sciences sequence IGE355-356 or IGE325 and IGE376 would be appropriate electives. Senior-year electives could include

IGE485 and IGE388. The applications of quantum mechanics requirement would be met best with Physics 454.

3. *Nuclear Engineering.* A student interested in nuclear engineering or nuclear science would be advised to select IEE210, IMG221, and IP217 as three of the sophomore engineering core sciences. Appropriate electives in later terms would be IP201 in term 5, IP609 as the required course in applications of quantum mechanics in term 7, and IP612 as a technical elective in term 7.

4. *Lasers and Quantum Electronics.* A student interested in lasers and quantum electronics may choose courses IP217, IEE210, and IMG221 for the sophomore engineering science requirement. During the junior year any of several courses may be appropriate; e.g., Physical Chemistry 389–390. The applications of quantum mechanics requirement should be met with either IP401 (fall term) or Physics 454 (spring term). The fall term technical elective might be Chemistry 681, Applied and Engineering Physics IP401, or Electrical Engineering IEE411. The recommended technical elective for the spring term of the senior year is Electrical Engineering IEE430. An alternative selection for senior-year technical electives, recommended for strong students, is the quantum electronics sequence IEE731–732.

Similar programs may be set up in other areas, such as plasma physics and materials science; examples are available at the office of the School of Applied and Engineering Physics. Students interested in this kind of interdisciplinary study are urged to develop programs that meet their specific objectives at the earliest possible time. They are advised to consult with one of the professors listed in this section under particular areas of interest or with the associate director of the School, P. L. Hartman.

The College Program Students who elect to develop a College Program (see pp. 38-42) may choose a major from an area of applied physics. A College Program major in nuclear engineering, for example, might include the applied and engineering physics courses IP201 and IP303, plus two of the four courses IP612, IP651, IP633, and IP609. Also available is a College Program in Energy Conversion, a synthesis of nuclear, thermal, and electrical engineering studies. This program is described on p. 39. Consultation with faculty members in the general area of the desired major must be made before embarking on a College Program.

Master of Engineering (Engineering Physics)

The primary objective of the fifth year of study in engineering physics is to provide an opportunity for advanced study; students who earn the M.Eng. (Engineering Physics) degree may move into development or research programs in applied physics in industrial or governmental institutions. The program may also serve as a preparation for more advanced graduate work in applied physics, or as exploratory study for the student interested in starting graduate work but not ready to make a commitment to a specific field. Finally, it provides an opportunity to satisfy prerequisite course work in certain new areas of graduate study which involve a combination of engineering or applied physics with another professional but nontechnical discipline.

General requirements for the M.Eng. degree, given on p. 13 permit considerable flexibility in the course program, and engineering physics students plan individual curricula in consultation with the program chairman. Specific requirements for the M.Eng. (Engineering Physics) degree are the following:

1. The required thirty credit hours must include a minimum of six in a graduate-level course sequence. The program must also include a graduate-level course in quantum mechanics and a fourth-year or graduate-level course in statistical mechanics, or their equivalents, unless such courses have been taken as part of the undergraduate program. In addition, the student must attend a sequence of approximately fifteen scheduled University seminars or colloquia chosen in consultation with the chairman of the program.

2. The project requirement may be satisfied by an informal study or project, experimental or analytical, which requires individual effort and is completed with a formal report. This carries at least six hours of credit. It is usually completed by the end of the second semester but permission to continue through the summer may be obtained. If the project is experimental, one course in mathematics or applied mathematics at the graduate level is required; if the project is analytical, one term in experimental laboratory physics at the graduate level or its equivalent must be taken. The study or project is chosen in consultation with the chairman of the program and is carried out under the personal direction of an appropriate member of the engineering or science faculty.

Inquiries about the study program, available facilities, admission requirements, or financial aid should be addressed to the Program Chairman, Master of Engineering (Engineering Physics), Clark Hall.

Master of Engineering (Nuclear)

This program is described under the Nuclear Science and Engineering section of this *Announcement*.

Master of Science and Doctor of Philosophy

The graduate program in the Field of Applied Physics provides a means for students with undergraduate training in physics to branch out into applied science while continuing the study of physics and for students with backgrounds in engineering or another science to extend their knowledge of physical science principles and techniques. A student may choose for specialization and thesis research any subject that involves the application of principles of physics and mathematics. The formal course programs leading to the M.S. and Ph.D. degrees contain a core of physics and mathematics courses, but individual programs of study are designed to meet the needs and interests of each student. Programs involving several academic disciplines and topics that are undergoing transition from fundamental physics to applied physics are readily accommodated.

Current areas of advanced study and research include: biophysics, chemical physics, physics of fluids, geophysics, nuclear and reactor physics, optics, plasma and thermonuclear physics, radiation and matter, solid state physics and materials science, space physics, and surface physics. Specific research projects in which graduate students in applied physics are currently participating include: tuneable laser Raman spectroscopy of the visual process, mechanisms of auditory organs, dynamics of biomolecular lipid and cell membranes, biochemical kinetics, electron microscopy of biomacromolecular structures, photosynthetic reaction centers, chemical lasers and molecular energy transfer, observations of critical phenomena in fluids using homodyne spectroscopy, electromagnetic sounding of the earth's mantle, analysis of nuclear structure by studies of the decay of short-lived radionuclides formed in a nuclear reactor, high-resolution electron microscopy and energy-analyzing electron microscopy, studies of quantum electronics using infared spectroscopy, experimental and theoretical studies on the confinement and heating of thermonuclear plasmas using relativistic electron beams, theoretical and experimental studies of plasma and hydrodynamic turbulence, statistical physics of amorphous systems, phase transformations at high pressures, quantum superconductivity and devices, atomic and microscopic properties of solid surfaces using photoemission electron tunnelling spectroscopy and electron diffraction, and experimental studies of atomic collisions and X-ray physics.

Details of the program, requirements for admission, and areas of advanced study are given in the *Announcement of the Graduate School* (see p. 4). A special Announcement, *Graduate Study in Engineering and Applied Science,* includes a section on applied physics. Further information may be obtained from the Graduate Faculty Representative (Applied Physics), Clark Hall.

Bioengineering

Bioengineering at Cornell is diverse, with specific bioengineering and premedical studies offered in the Division of Basic Studies and most of the upperclass engineering fields. Normally, students interested in bioengineering complete their engineering and basic science prerequisites, including biology and organic chemistry, during their freshman and sophomore years. In the junior and senior years, students pursue bioengineering options within their chosen engineering fields by choosing their electives to support their special goals without detracting from the essential engineering foundation provided by a Field Program.

When pursuing a biological emphasis in an organized degree-granting undergraduate field, students receive outstanding preparation in the particular field of engineering, plus the background to apply this knowledge in diverse areas of ecology, biology, or medicine. By careful selection of electives a student will complete the senior year with the educational option of: (1) further graduate study in biology, ecology, or medicine, or (2) additional study in the engineering field. The wisdom of retaining two options has proved itself; the faculty of the College is strongly committed to the idea that students be adequately prepared engineers with a variety of options upon graduation.

A few students have sufficient experience to decide upon an area of specialization without retaining other options. For these students an individualized curriculum can be designed within the College Program (see p. 39). This Program has been used effectively by students whose principal educational aim was matriculation in a medical college and by a few bioengineering students who wished to combine different engineering emphases. Since there is no set curriculum in the College Program, the key to formulating a viable bioengineering course of study lies in working with appropriate faculty advisers who are knowledgeable in the major and minor areas of concentration. Suggestions for suitable faculty advisers may be obtained from the Advising and Counseling Center, 170 Olin Hall.

During the first two years, all students in the College of Engineering are enrolled in the Division of Basic Studies to pursue a program combining specified course work with electives appropriate to their field of interest.

The following program is suggested as a guide; it is understood that each bioengineering student will discuss his or her plans carefully with a faculty adviser before making decisions regarding a course of study.

Term 1	*Credits*
Mathematics 191, Calculus for Engineers	4
Chemistry 207, General Chemistry	3
Engineering IBE105, Elements of Engineering Communication	3
Biological Sciences 101 and 103, or 105, or 109*	4
Liberal studies elective	3
Term 2	
Mathematics 192, Calculus for Engineers	4
Chemistry 208, General Chemistry	3
Biological Sciences 102 and 104, or 106, or 110*	4
Physics 112, Physics I: Mechanics and Heat	4
Liberal studies elective	3
Term 3	
Mathematics 293, Engineering Mathematics	4
Physics 213, Physics II: Electricity and Magnetism	4
Engineering core science	3
Chemistry 253, Elementary Organic Chemistry	4
or	
Chemistry 357, Introductory Organic Chemistry†	3
Liberal studies elective	3
Term 4	
Mathematics 214, Engineering Mathematics	3

Physics 214, Physics III: Optics, Waves, and Particles	3
Engineering core science	3
Chemistry 251, Elementary Organic Laboratory	2
or	
Chemistry 358, Introductory Organic Chemistry†	3
Liberal studies elective	3

**Either* Biological Sciences 101 and 103, 102 and 104, or 105 and 106 are recommended for biology majors and will serve satisfactorily for premed students; alternatively, the nonmajor courses 109 and 110 could be chosen. Students who are free to attend Summer Session may wish to take the biology sequence, in whole or in part, during the summer, as this eases the work load during the academic year.
†Students are encouraged to discuss with their advisers whether chemistry is appropriate to their interests and which chemistry courses are most suitable. (Chemical engineering majors would choose Chemistry 287, 289, 288, 290, Physical Chemistry.)

Using this curriculum as a basic guide, students should consult their advisers regarding possible variations that might stress particular needs or unusual situations. Current copies of *Medical School Admissions Requirements,* which lists appropriate courses, are available in the Advising and Counseling Center, along with catalogs from many universities that offer graduate bioengineering programs.

The many course programs available to bioengineering students in upperclass engineering fields cannot be described in this *Accouncement* because of space limitations. Detailed descriptions of these course offerings and suggested curricula are, however, essential for bioengineering students who are seeking to make an intelligent decision regarding a field of study for the junior and senior years. Before preregistering for the sophomore year, bioengineering students should obtain from the Engineering Advising and Counseling Center, a copy of *Bioengineering at Cornell,* which provides the information necessary for putting the decision-making process in perspective.

Chemical Engineering

Olin Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Chemical), Master of Science, Doctor of Philosophy.

J. C. Smith, director; J. L. Anderson, J. R. Anderson, K. B. Bischoff, G. G. Cocks, R. K. Finn, P. Harriott, F. Rodriguez, G. F. Scheele, M. L. Shuler, J. F. Stevenson, R. G. Thorpe, R. L. Von Berg, H. F. Wiegandt, R. York.

Courses of instruction are listed on pp. 74–77.

Chemical engineering involves the application of the principles of the physical sciences and mathematics and of engineering judgment to fields in which matter is treated to effect a change in state, energy content, or chemical composition. Many chemical engineers are employed in the process industries, in which raw materials are converted to useful products such as industrial chemicals, petroleum products, metals, rubbers, plastics, synthetic fibers, foods, paints, and paper. Because of their knowledge of chemistry, chemical engineers also are prepared to serve in related fields such as biochemical and biomedical engineering, nonmetallic materials, waste disposal, and pollution abatement.

An integrated program in chemical engineering leads to a Bachelor of Science degree at the end of four years and to a Master of Engineering degree in one additional year. The curriculum applies the latest developments in the fields of chemistry, mathematics, physics, and the engineering sciences to chemical engineering concepts and provides enough flexibility so that students may prepare themselves for the broad application of these concepts to many engineering problems. A four-year sequence of liberal studies electives provides an opportunity to attain a background in the social sciences, economics, or other nontechnical subjects. Free electives in the upperclass years permit the choice of additional courses in such fields. Free and technical electives may be used to broaden the student's preparation in the sciences and engineering or to study specialties in more depth. The School of Chemical Engineering offers special programs in biological engineering, polymeric materials, and chemical microscopy. Students may also use their electives to attain greater proficiency in fields such as chemistry, mathematics, biology, environmental systems engineering, water resources, computer science, or nuclear engineering.

Laboratory and Research Facilities

All Cornell programs in chemical engineering, both undergraduate and graduate, are given in Olin Hall of Chemical Engineering. This modern and well-equipped building, with over 100,000 square feet of floor space, provides lecture and recitation rooms as well as laboratories for instruction and research. The main laboratory extends through three floors and contains pilot-plant equipment for undergraduate projects and research as well as space for research apparatus for graduate students. Shops, storage, and service facilities are adjacent to this laboratory.

In addition, a large portion of the building is devoted to small-unit laboratories containing furniture and equipment suitable for the chemical and bench-scale projects and research carried out by both undergraduate and graduate students. Specialized laboratories are also available. The Geer Laboratory for Rubber and Plastics has facilities for making, processing, and testing all types of polymeric materials. The biochemical engineering laboratory contains equipment for fermentation and other biochemical processes; the process control area is equipped with control instruments, recorders, and computers.

The Degree Programs

Bachelor of Science

The Field Program in Chemical Engineering offers a coordinated sequence of chemical engineering courses beginning in the sophomore year and extending through the fourth year.

Course programs for terms 1 through 4 are described under the Division of Basic Studies. Underclass students who plan to enter the professional chemical engineering program register for Chemistry 287–288, Chemistry 289–290, and Chemical Engineering IHE110 or IHE111 during the sophomore year.

The program for the upperclass years is as follows:

Term 5	*Credits*
Chemistry 357, Organic Chemistry	3
Chemistry 251, Organic Chemistry Laboratory	2
IHE311, Equilibria and Staged Operations	3
IHE430, Introduction to Rate Processes	3
Elective†	3
Liberal studies elective	3
Term 6	
Chemistry 358, Organic Chemistry	3
IHE321, Materials*	5
IHE431, Analysis of Separation Processes	3
Elective†	3
Liberal studies elective	3
Term 7	
IHE312, Chemical Engineering Thermodynamics	3
IHE432, Chemical Engineering Laboratory	3
IHE461, Chemical Process Evaluation	3
Elective†	3
Liberal studies elective	3
Term 8	
IHE410, Reaction Kinetics and Reactor Design	3
IHE462, Chemical Process Synthesis	4
Electives†	6
Liberal studies elective	3
IHE101, Nonresident lectures	0

*Students who have an approved plan for concentration in a minor topical area and who require more elective courses than the number scheduled to accomplish their goals may substitute additional electives for IHE321, Materials (provided that ITE261, Mechanical Properties of Materials, has been chosen as an engineering core science during the sophomore year). This option could be of interest to students planning concentrations in such areas as biological engineering, environmental studies, advanced chemistry, and systems and operations research.

†The electives in Terms 5 to 8 must comprise three hours of the postponed engineering core science course (see the section on Basic Studies); six hours of technical electives; and at least six hours of free electives.

The College Program. Students pursuing a College Program, described on p. 38, may elect a major or a minor in chemical engineering. These majors and minors require a sequence of chemical engineering courses in the third and fourth years, plus the proper prerequisites, as specified by the student's adviser and the College Program Committee.

Master of Engineering (Chemical), Master of Science, and Doctor of Philosophy

A student holding a baccalaureate or equivalent degree in chemical engineering from a college of recognized standing is eligible to pursue advanced work leading to a professional degree, Master of Engineering (Chemical), or to the general degrees M.S. or Ph.D., with majors in chemical engineering.

The professional master's degree, M.Eng. (Chemical), is awarded at the end of one year of study with successful completion of thirty credit hours of required and elective courses in technical fields including engineering, mathematics, chemistry, physics, and biology. Courses emphasize design and optimization based on the economic factors that affect process, equipment, and plant design alternatives. No thesis is required, but a design project is involved in the required courses. Further information may be obtained from the Director of Chemical Engineering, Olin Hall.

The M.S. and Ph.D. degrees are administered by the Graduate School and require work in both major and minor fields of study, as well as the completion of a thesis involving individual experimental research or analytical investigations. A student interested in these degrees should consult the *Accouncement of the Graduate School* and an Announcement titled *Graduate Study in Engineering and Applied Science* (see p. 4). Prospective candidates may also communicate with the Graduate Faculty Representative (Chemical Engineering), Olin Hall.

Civil and Environmental Engineering

Hollister Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Civil), Master of Science, Doctor of Philosophy.

W. R. Lynn, director; G. B. Lyon, assistant director; J. F. Abel, V. C. Behn, D. J. Belcher, J. J. Bisogni, W. H. Brutsaert, F. J. Cesario, L. B. Dworsky, G. P. Fisher, R. H. Gallagher, C. D. Gates, P. Gergely, D. A. Haith, J. N. Kay, A. Wm. Lawrence, T. Liang, J. A. Liggett, P. L-F. Liu, R. C. Loehr, D. P. Loucks, W. McGuire, A. J. McNair, A. H. Meyburg, P. J. Murphy, A. H. Nilson, T. Peköz, D. A. Sangrey, R. E. Schuler, R. G. Sexsmith, C. Shoemaker, F. O. Slate, R. N. White, R. W. Willis.

Courses of instruction are listed on pp. 78–89.

Civil and environmental engineering deals primarily with the large fixed works, systems, and facilities that are basic to community living, industry, and commerce and vital to man's well-being. The planning, design, construction, and operation of transportation systems, bridges, buildings, water and sewage treatment facilities, dams, and other major artifacts of society are civil and environmental engineering activities. Civil and environmental engineers are major contributors to the solution of problems of urbanization, city planning, and environmental quality control. A burgeoninig national population and the desire of people to cluster in city complexes require a great increase in the number of well-prepared engineers who can meet the basic needs of society with efficiency, economy, and safety.

The wide range of subjects which are concerns of civil and environmental engineers are generally grouped into a number of subfields and specializations. At Cornell, there are two subject departments in the School of Civil and Environmental Engineering—Structural Engineering and Environmental Engineering—and a Program in Environmental Sensing, Measurement, and Evaluation. The major areas in the Department of Structural Engineering are: analysis, behavior, and design of structures; structural materials; and soils and foundations. Within the Department of Environmental Engineering there are five major areas: environmental quality engineering; fluid mechanics and hydrology; public systems and environmental systems engineering; transportation; and water resources planning and analysis.

These units provide courses for graduate study leading to advanced degrees and also those courses necessary to support the undergraduate curriculum in civil and environmental engineering.

The Degree Programs

The undergraduate field curriculum in civil and environmental engineering leads to the degree of Bachelor of Science. It provides a thorough foundation in the basic sciences, applied sciences, and mathematics that are fundamental to the profession. It also includes an introduction to the major areas of modern civil and environmental engineering technology and substantial opportunity for liberal study.

Most students go on to graduate study after completion of the baccalaureate. The three main paths of advanced work at Cornell are:

1. Graduate study in the Field of Civil and Environmental Engineering leading to the degree of Master of Engineering (Civil). This is the first degree with a civil engineering designation. It is obtained upon completion of a curricular program of thirty credit hours of advanced study, including an extensive design project. The M.Eng. (Civil) program is designed primarily for students who intend to enter the professional practice of engineering, and the degree represents attainment of an educational level considered essential for modern practice.

2. Graduate study leading to the degrees Master of Science and Doctor of Philosophy. These degrees are intended primarily for students who plan careers in research, development, or teaching in an area of civil and environmental engineering.

3. Advanced study in a related technical field such as applied mechanics, aerospace engineering, or urban planning, or in a nontechnical field requiring an engineering background, such as law or business administration.

Bachelor of Science

The first four terms are described in the section on the Division of Basic Studies. The Basic Studies program specifies that two engineering core science courses be taken in each term of the sophomore year. Mechanics of Solids IAK221, is required for entry into the Civil and Environmental Engineering Field Program. It is recommended, but not required, that students planning to enter this field take IOR260, Introductory Engineering Probability, and either IAK231, Dynamics, or ITE261, Mechanical Properties of Materials, as two of their other sophomore engineering core science courses.

The following recommended sequence of courses is intended to provide an introduction to the several diverse areas within the Field of Civil and Environmental Engineering and to permit more detailed study in at least one area. Students with a well-defined special interest may choose to depart from this sequence. In such cases, a special program should be developed by the student in consultation with a faculty adviser of his or her choice within the field, preferably prior to the fifth semester, and submitted to the Field Curriculum Committee for approval. It is advisable for a student to submit an application for a special program as early as the first term of the sophomore year.

Term 5	*Credits*
IAK231, Dynamics*	3
IIC301, Fluid Mechanics	3
IIG301, Structural Engineering I	4
IOR260, Introductory Engineering Probability*	3
Liberal studies elective	3
Term 6	
ITE261, Mechanical Properties of Materials*	3
IIE301, Environmental Quality Engineering	3
IID301, Soil Mechanics	3
IIB303, Engineering Economics and Systems Analysis	3
Liberal studies elective	3
Term 7	
Civil and environmental engineering distribution courses (2)†	6
Technical elective	3
Free elective	3
Liberal studies elective	3
Term 8	
Civil and environmental engineering distribution courses (2)†	6
Technical elective	3
Free elective	3
Liberal studies elective	3

*Satisfactory completion of these engineering core science courses in the Division of Basic Studies increases the number of technical electives accordingly.

†There are distribution requirements for the civil and environmental engineering distribution courses. The student may obtain information on these requirements from his or her faculty adviser.

The College Program As an alternative to the Field Program, a student with a strong interest in an interdisciplinary specialized program may wish to consider the College Program (see p. 38). Where this involves one of the areas of civil and environmental engineering, either as a major or minor subject, the various department faculty members are prepared to advise and assist the student upon request. Examples of College Programs are those combining study in structural engineering and architecture, transportation engineering and urban planning, environmental systems engineering and operations research, sanitary engineering and oceanography, public systems planning and analysis, and survey engineering.

Master of Engineering (Civil)

The master of Engineering (Civil) degree is designed to prepare a student for professional practice in civil and environmental engineering. General requirements for the program, in addition to those stated on p. 13, include four required courses; two in professional engineering practice, IIK520 and IIK521; and two in design, IIK510 and IIK511 or the equivalent. The second course in design requires the completion of a project involving synthesis, analysis, decision making, and application of engineering judgment. It is offered as an intensive, full-day, three-week course during the winter intersession.

The remainder of a student's program of studies is designed individually in consultation with an academic adviser and then submitted to the School's Professional Degree Committee for approval. The objectives in course planning are to provide breadth in the fundamentals of civil and environmental engineering, and specialization in one area with some concentration in a related area. Most students will have achieved the necessary breadth during their undergraduate years. Some, however, may require additional course work in the graduate program to fulfill the breadth requirement. Students in the School of Civil and Environmental Engineering may avail themselves of a number of graduate course offerings in fields related to their major interest but outside of the school.

Further information on this program may be obtained from the Director, School of Civil and Environmental Engineering, Hollister Hall.

Master of Science and Doctor of Philosophy

The requirements for the degrees of Master of Science and Doctor of Philosophy are described in the *Announcement of the Graduate School.* These are degrees oriented toward research and require submission of a thesis.

In the field of Civil and Environmental Engineering, a number of special areas of concentration are available as either major or minor subjects. These concentrations are identified with the departments of Structural Engineering and Environmental Engineering, and with the Program in Environmental Sensing, Measurement, and Evaluation, which provide related graduate instruction.

A number of fellowships and assistantships are available to graduate students in civil and environmental engineering. Prospective graduate students should consult the *Announcement of the Graduate School* and a special Announcement, *Graduate Study in Engineering and Applied Science* (see p. 4). Further information may be obtained by writing to the Graduate Faculty Representative (Civil and Environmental Engineering), Hollister Hall.

Department of Structural Engineering

R. H. Gallagher, chairman; J. F. Abel, P. Gergely, J. N. Kay, W. McGuire, A. H. Nilson, T. Peköz, D. A. Sangrey, R. G. Sexsmith, F. O. Slate, R. N. White.

Structural engineering comprises the analysis and design of structures of all types, those traditionally identified with civil engineering (e.g., buildings, bridges, watertanks, dams, and foundations) as well as those connected with other branches of engineering (e.g., aerospace structures, pressure vessels, and nuclear engineering structures). Soil mechanics and foundation engineering are concerned with the measurement of soil and rock properties and their use in the design process. The Department of Structural Engineering is responsible for undergraduate and graduate instruction and for research in all these areas. In addition, instruction and research in civil engineering structural materials (e.g., concretes, asphalts, structural metals, and soils) are the Department's responsibility.

Instruction, both undergraduate and graduate, emphasizes fundamental understanding of structural behavior and modern methods of design and analysis, many of them computer-oriented. A large volume of research, sponsored by governmental agencies and industry, is carried out in four large and fully equipped laboratories: a structural laboratory for full-scale testing, a models laboratory, a versatile cement and concrete laboratory, and a soil mechanics laboratory with a wide variety of both standard and specialized equipment.

Department of Environmental Engineering

D. P. Loucks, chairman; V. C. Behn, J. J. Bisogni, W. H. Brutsaert, F. J. Cesario, L. B. Dworsky, G. P. Fisher, C. D. Gates, D. A. Haith, A. Wm. Lawrence, J. A. Liggett, P. L-F. Liu, R. C. Loehr, W. R. Lynn, A. H. Meyburg, P. J. Murphy, R. E. Schuler, C. Shoemaker, R. L. Willis.

Environmental engineering is concerned with the principles, technology, and methodology for solving problems related to the quality of the environment as well as with the impact of their application upon society.

A successful career in environmental engineering requires the ability to contribute to the planning, design, evaluation, and analysis of technological innovations for improving environmental quality in response to ever-changing goals and needs of society. Creativity and adaptability to change are also necessary for a successful career in environmental engineering in industry, governmental agencies, consulting engineering practice, research institutes, or colleges or universities. The Department of Environmental Engineering stresses the basic sciences as well as the applied mathematical, engineering, economic, and legal considerations needed for leadership in this rapidly expanding profession.

Undergraduate students can concentrate in environmental engineering within the curriculum of the School of Civil and Environmental Engineering by selecting a distribution course, technical electives, and free electives in this area. Candidates for the Master of Engineering (Civil) degree can also specialize in this area. Candidates for the Master of Science and Doctor of Philosophy degrees can develop extremely flexible programs, utilizing their prior experience in this area. Each graduate student in environmental engineering is expected to complete significant independent research for the M. S. or Ph.D. degree, or an engineering design for the M.Eng. (Civil) degree. (Also see the section on Degree Programs above.)

Because teaching and research in environmental engineering continue to evolve, the faculty has skills in many areas, including economics, policy analysis, law, and planning, in addition to engineering. The Department is committed to the multidisciplinary solution of environmental engineering problems, and maintains a close association with other departments in the University. Faculty members in these other departments often serve as members of graduate students' committees.

Students, through their studies, will gain greater depth in their particular areas of interest, as well as a detailed understanding of the multidisciplinary character and complexity of the type of problems that they will be called upon to solve. The Department of Environmental Engineering provides a unique opportunity for students to achieve the desired levels of proficiency in particular specialties, while retaining the perspective and versatility that will be expected of them in a world in which the environmental problems are changing but the basic fundamentals are not.

For the student planning a program of study, it is useful to subdivide the departmental teaching and research activities into five broadly defined and somewhat overlapping subject areas: environmental quality engineering, fluid mechanics and hydrology, public and environmental systems engineering, transportation, and water resources planning and analysis. Faculty in the Department are frequently active in more than one of these subject areas. Prospective graduate students are encouraged to write or visit with any faculty member in their areas of interest in order to obtain more information regarding courses or current research activities.

Environmental Quality Engineering

This study area is concerned with the phenomena, concepts, methods, and technology essential for the maintenance of the quality of the air-water-land environment. Instruction and research concentrate on the pertinent biological, chemical, and physical phenomena, and on the mathematical, engineering, laboratory, and computer skills needed for successful planning, design, and management of the engineering processes, facilities, and systems necessary to achieve environmental quality objectives.

Experimental facilities include controlled-temperature rooms, water-microbiology and water-chemistry laboratories, and rooms especially equipped for bench and pilot-level unit process studies. Computer terminals are also available for student use.

Fluid Mechanics and Hydrology

Understanding and proper application of the principles of fluid mechanics, hydraulics, and both ground and surface water hydrology are essential for the solution of many environmental engineering and water-resources planning problems, especially those affected by the hydrologic cycle. Such problems include the dispersion of residual materials and heat energy in ground and surface waters and in the atmosphere, the flow of water over and through natural soil and rock, drought and flood prediction and control, the circulation and stratification of water in lakes and oceans, propagation and impact of waves in the estuarine and coastal environment, and sediment transport.

The hydraulics laboratory is well equipped for demonstrations and experiments in wave mechanics and rotating flows and for a variety of other experiments.

Environmental and Public Systems

This subject area involves the application of systems analysis methods, economic and political theory, technology assessment, and environmental law to public sector problems, including: the planning, design, and operation of public health services; urban noise management; the evaluation and control of the impacts of new technology; and other environmental quality and urban and regional planning problems. It is concerned with the development of improved methods for defining and evaluating public investment alternatives, for predicting the demand for public and environmental service facilities, for planning engineering projects, for controlling disease and crime, for improving the level of nutrition in developing regions, for land-use planning, etc. This subject area focuses also on the applicable environmental engineering technology, economic theory, legal procedures, and computer optimization and simulation methods.

Graduate students interested in these subject areas may specialize in environmental systems engineering. Undergraduates may elect to take a College Program in Environmental and Public Systems (see p. 41).

Transportation

The major emphasis in this area of teaching and research is in the application of analytical techniques to the handling of transportation problems. All means of transport are considered, with special emphasis on transportation problems in urban areas. Specific interests of faculty members lie in the areas of demand modeling for passenger and freight movements, the development of mass transit systems, airport planning and operations, traffic flow theory, transportation systems analysis, and highway design.

Undergraduates may elect to specialize in the area of transportation engineering and planning through the Field Program in Civil and Environmental Engineering, or by enrolling in a College Program in Environmental and Public Systems (see p. 41). Students interested in the physical planning and design of transportation facilities may develop programs that include courses in soil mechanics; structures; fluid mechanics and hydrology; and environmental sensing, measurement, and evaluation.

Water Resources Planning and Analysis

This study area includes both qualitative and quantitative aspects of multiobjective, multipurpose water-resources policy planning and analysis. Easy access to the substantial collection of documents available in a separate water-resources section of the College of Engineering Library and in the Water Resources and Marine Sciences Center (an interdisciplinary, University unit) provides an excellent opportunity for students to select topics for study and research from a wide variety of relevant sources.

Comprehensive river-basin planning and development are examined from historical and contemporary points of view, and students are encouraged to become involved in case studies of current problems of water-resources planning. Various quantitative planning models that integrate the economic, political, and engineering aspects of water quantity and quality planning and management are the subjects of a variety of courses in water resources systems analysis. Students who major in water resource systems at the Ph.D. level are expected to contribute to the further development and application of these multidisciplinary, quantitative planning techniques.

Program in Environmental Sensing, Measurement, and Evaluation

D. J. Belcher, T. Liang, G. B. Lyon, A. J. McNair.

The design and construction of civil and environmental engineering works require detailed consideration of present and potential uses of the earth's surface and resources. The Program in Measurement and Remote Sensing is concerned with the sensing, measurement, and evaluation of these related uses.

The techniques of the interpretation of aerial photographs and other remote sensing images, coupled with ground observations, are used to establish the overall nature of the environment, define problems, and aid in their solution. Earth measurement involves surveying, geodesy, photogrammetry, and the related computing and data presentation methods.

The versatile laboratories for both instruction and research in these areas are well equipped with several modern stereoplotters and representative geodetic instruments. The Program maintains a large collection of aerial photographs and images from all over the world which are used in photogrammetric and aerial photographic studies.

The College Program

170 Olin Hall

Degree Offered: Bachelor of Science.

College Program Committee: S. Linke, Y.-H. Pao, R. Phelan, D. L. Turcotte, R. L. Von Berg, W. W. Webb. Program coordinator: J. H. Pirko, 170 Olin Hall.

The College Program offers engineering students an opportunity to pursue novel and interdisciplinary courses of study when educational needs and career objectives cannot be satisfied by one of the traditional Field Programs of the College.

Each College Program is individualized, consistent with the student's special interests, and is developed by the student in consultation with faculty advisers. Every College Program, with the exception of certain sponsored programs discussed below, must comprise an engineering major and a minor, together forming a coherent curriculum which meets well-formulated educational objectives. The major may be taken in any subject area offered by schools or departments of the College. The minor may be in a second engineering subject area, or in a logically connected nonengineering area.

Some recent examples of major and minor combinations are: air-photo interpretation and conservation or geology; computer science and electrical systems or industrial engineering; electrical engineering and industrial engineering; electrical systems and biological science or computer science; theoretical and applied mechanics, and aerospace engineering, biological science, or materials science; environmental quality and ecology; environmental systems and city planning or regional planning; industrial engineering and computer science; materials science and biological science or chemistry; mechanical engineering and biological science or oceanography; geology and oceanography; and transportation and regional planning.

Whatever combination is elected must clearly form, in scope and in substance, an engineering education, and should include engineering design and synthesis as well as engineering sciences.

Graduates of the College Program have pursued careers and advanced studies in physical sciences, medicine, business, and law, as well as in engineering. Therefore, in planning a College Program, students should consider carefully their future educational and professional objectives and, in particular, the prerequisites for any formal graduate study in which they may be interested, as well as requirements for professional engineering licensing.

Admission

Students apply to enter the College Program at the beginning of the second term of the sophomore year. Entry is in the junior year, after all requirements of the Division of Basic Studies have been met. The application must include a statement of objective and a listing of proposed courses clearly identified by title, number, and credit hours.

A student may receive assistance in developing his or her program from professors in the proposed major and minor subject areas who may be recommended by the College Program Committee or already encountered by the student.

Application forms and information may be obtained from the College Program Office, 170 Olin Hall. After the application has been endorsed by the professors representing the proposed major and minor areas, it is submitted to this Office and is then either approved or disapproved by the College Program Committee. An approved program is the curricular contract to which the student must adhere. A College Program proposal which constitutes only a minor departure from an established Field Program will not be approved.

Degree Requirements

Once admitted to the College Program, students progress under the supervision of the College Program Committee. Their advisers are the faculty members who endorsed their programs, and any course changes must be approved by them. A change in the major or minor area, or any extensive change in courses that substantially alters the original thrust of the program, or cumulative substitutions having the same effect, must be approved by the Committee, which is responsible for all of the administrative functions normally performed by the faculty of a Field Program.

Specific requirements for the Bachelor of Science degree in a College Program are: (1) An approved program of fourteen major and minor courses, at least seven of which must be in engineering. These must carry a minimum of forty-two credit hours, of which at least twenty-one are to be in engineering subjects. (2) Four liberal studies elective courses, giving a minimum of twelve hours of credit. (3) Two free elective courses, giving a minimum of six hours of credit.

Special Sponsored College Programs and Majors

College Programs in Bioengineering

A student who is interested in bioengineering or engineering-oriented premedical preparation usually will find it advantageous to follow one of the organized bioengineering options offered within the Field Programs. If the field options do not provide a suitable program, an individualized College Program may be formulated. (See also Bioengineering, p. 32.)

College Program Major in Computer Science

A student interested in concentrating in the area of computer science during the upperclass years should consult with a faculty member from the Department of Computer Science, who will help in formulating an appropriate College Program. A minimum grade-point average of 2.5 is usually required. A typical computer science major might consist of the following courses offered by the Department of Computer Science.

ICS211, Computers and Programming (engineering core science)
ICS280, Discrete Structures
ICS314, Introduction to Computer Systems and Organization
ICS321, Introduction to Numerical Analysis
ICS410, Data Structures
ICS411, Programming Languages
ICS414, Systems Programming and Operating Systems
ICS481, Introduction to Theory of Computing
ICS612, Translator Writing

There is considerable flexibility in devising a College Program in Computer Science. Courses other than the ones listed above may be taken, depending on the student's interests. This major must be combined with a suitable supporting minor subject.

College Program in Energy Conversion

Students who want a broadly based engineering curriculum aimed at meeting the accelerating energy needs of society should consider the College Program in Energy Conversion, which combines elements of three conventional disciplines: nuclear, thermal, and electrical engineering. Interested students should consult a member of the faculty group sponsoring the College Program in Energy Conversion: K. B. Cady and D. D. Clark (nuclear engineering), Ward Laboratory of Nuclear Engineering; B. J. Conta and F. K. Moore (thermal engineering), Upson Hall; and S. Linke and C. B. Wharton (electrical engineering), Phillips Hall.

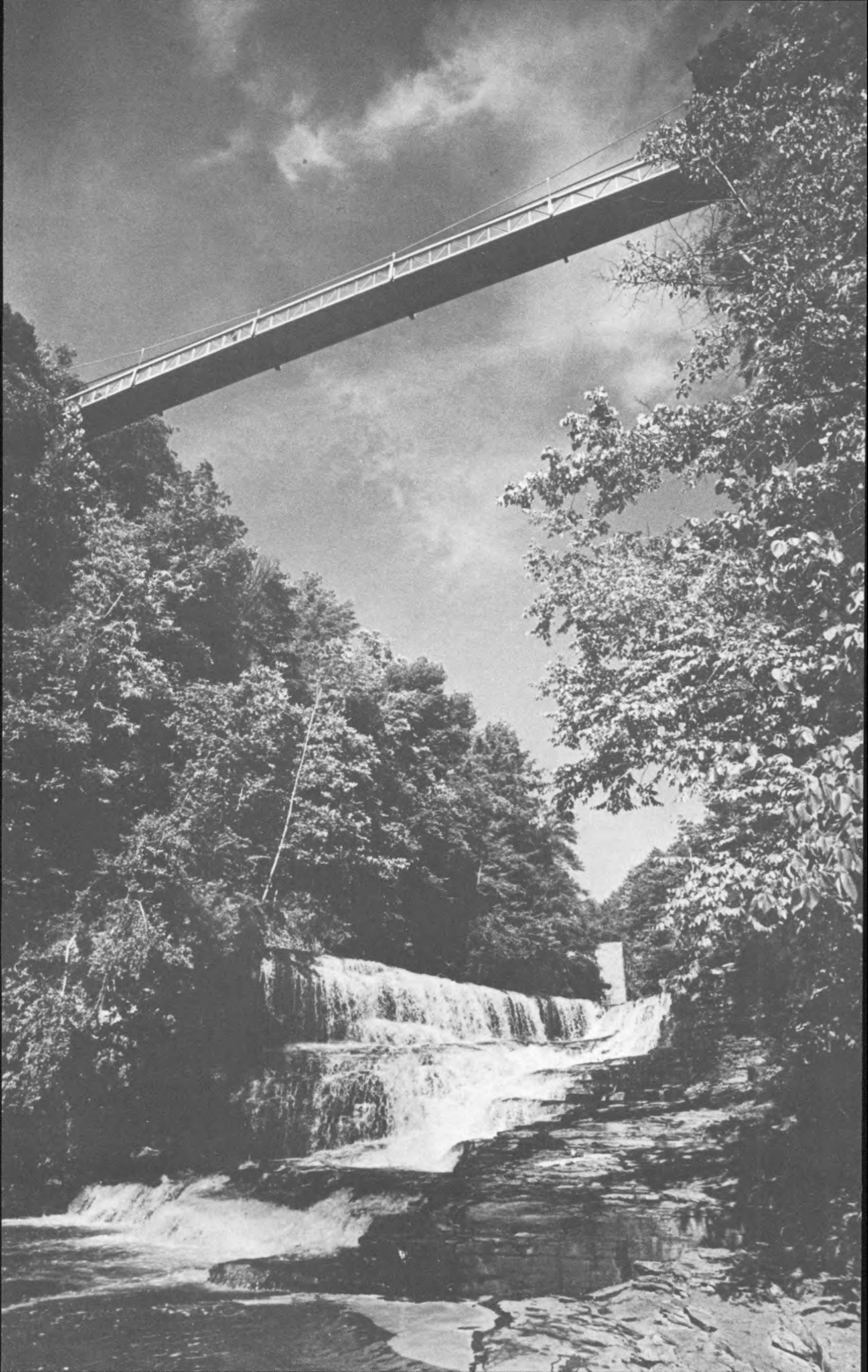
A typical curriculum is outlined below. This sample curriculum assumes that the student has included IMG221, Introduction to Thermodynamics, and IEE210, Introduction to Electrical Systems, as two of the sophomore engineering core sciences.

Term 5
IAA350, Advanced Engineering Analysis I
IMF323, Fluid Mechanics
IEE315, Electrical Laboratory I
IP201, Nuclear Energy and the Environment
Liberal studies elective

Term 6
IAA351, Advanced Engineering Analysis II
IMP455, Energy Conversion
IEE316, Electrical Laboratory II
IP303, Nuclear Science and Engineering
Liberal studies elective

Term 7
IMF324, Heat Transfer and Transport Processes
IEE651, Electric Energy Systems I
IP612, Nuclear Reactor Theory I
Free elective
Liberal studies elective

Term 8
IMP441, Power Systems
IEE652, Electric Energy Systems II
IP651, Nuclear Measurements Laboratory
Free elective
Liberal studies elective



By use of electives and substitutions and with attention to prerequisites, the student may include several of the following:

IEE671, Feedback Control Systems I
IEE672, Feedback Control Systems II
IEE680, Elementary Plasma Physics and Gas Discharges
IEE681, Introduction to Plasma Physics
IMF636, Turbomachinery
IMG656, Advanced Thermal Engineering Laboratory
IMP442, Pollution Problems
IMP643, Combustion Theory
IP633, Nuclear Reactor Engineering
IP634, Nuclear Engineering Design Seminar
IIB303, Engineering Economics and Systems Analysis
Bio. S.102, Biological Sciences

College Program in Engineering Science

Faculty members of the Department of Theoretical and Applied Mechanics have formulated a program in engineering science which they are prepared to endorse. The program has the general format outlined below.

Term 5
Engineering science
Thermodynamics
Mathematics or engineering analysis*
Physics or engineering science
Liberal studies elective

Term 6
Engineering science
Fluid mechanics
Mathematics or engineering analysis*
Physics or engineering science
Liberal studies elective

Term 7
Physics or engineering science
Mathematics or engineering analysis*
Intermediate dynamics
Free elective
Liberal studies elective

Term 8
Physics or engineering science
Mathematics or engineering analysis*
Continuum mechanics
Free elective
Liberal studies elective

*Substitution of a one-year course in experimental mechanics or physics for a one-year course in mathematics may be arranged.

College Program in Environmental and Public Systems

In recent years, systems analysis has been widely used to aid in the planning and management of environmental quality and public systems. Students who wish to major in this area generally will choose one of the following specialties: *water resources, ecosystem management, transportation,* or other studies of *public systems.* A list of suggested course selections for each of these specialties may be obtained from the Department of Environmental Engineering, 307 Hollister Hall. The following core courses or their equivalents are required for all specialties.

Systems Analysis:
IOR320–321, Optimization Models and Methods in Industrial Engineering and Operations Research I and II
IOR361, Probabilistic Models in Industrial Engineering and Operations Research
IOR370, Introduction to Statistical Theory with Engineering Applications
IOR260, Introductory Engineering Probability*

Economics:
IIB201, Economic Analysis of the Private Sector (Microeconomics)
IIB202, Economic Analysis of Government

Public Systems:
IIB617–618, Public Systems Analysis I and II

Transportation:
IIF621, Urban Transportation Planning I

The balance of the program will be determined by the student and his or her adviser. Students are reminded that faculty members of the department are available to work with them as advisers in arranging individualized College Programs to meet specific needs and career interests.

*This would normally be taken as an engineering core science in fulfillment of Division of Basic Studies requirements.

College Program in Regional Science

This is an interdisciplinary course of study that embraces economics, statistics, planning, and engineering, in order to deal with locational, regional, and other spatial considerations in the planning of engineering works and the assessment of environmental impacts. Water resource, transportation, and air quality control projects are examples of developments that cannot be effectively planned and implemented without an understanding of their regional setting and that involve consideration of both the behavior of decision makers and institutions and the preferences of an affected populace.

Students interested in this program should consult the program coordinator, F. J. Cesario of the civil and environmental engineering faculty. Required core courses are the following.

Economics:
IIB201, Economic Analysis of the Private Sector
IIB202, Economic Analysis of Government

Systems Analysis:
IOA270, Basic Engineering Statistics*
IOA335, Introduction to Game Theory
IOE614, Facilities Location and Design
IOE622, Operations Research I

Regional Science:
Public Policy and Regional Analysis 915, Location Theory (Same as Regional Science 769)
Public Policy and Regional Analysis 933, Methods of Regional Analysis

*It is strongly recommended, although not required, that Economics 320 be taken also.

In addition, six courses must be chosen from among the four applications areas listed below. At least three are to be taken from one area, and one from each of the other areas.

Environmental Quality:
IIB619, Environmental Systems Analysis
IIE633, Environmental Quality
IIE634, Air Quality Control
IIB747, Environmental Policy Analysis

Transportation:
IIF620, Transportation Engineering
IIF621, Urban Transportation Planning I
IIF623, Urban Transportation Planning II
IIF624, Transportation Systems Analysis
IIF643, Design and Planning of Mass Transportation
IIF644, Transportation Systems Evaluation

City and Regional Planning:
Public Policy and Regional Analysis 410, Introduction to Urban and Regional Theory
Public Policy and Regional Analysis 832, Simulation in Planning and Policy
Urban Planning and Development 512, Urban Economic Analysis
IIH718, Water Resource Systems

Regional and Development Economics:
Economics 371, Process of Economic Development
Economics 378, Economics, Population, and Development
IIB617, Public Systems Analysis I
IIB618, Public Systems Analysis II
Urban Planning and Development 824, Econometric Methods in Regional Planning

College Program in Survey Engineering

Cornell students interested in developing competence in directing or performing surveys at the professional level may enroll in a recently organized College Program in Survey Engineering. This program has been formulated by faculty from the Program in Environmental Sensing, Measurement, and Evaluation of the School of Civil and Environmental Engineering, and from the Department of Agricultural Engineering, who are prepared to assist students in formulating a suitable course of study.

Surveying is concerned with obtaining the location, size, direction, and other geometrical characteristics of physical features on, in, or near the earth. Surveying and mapping are necessary prerequisites for, and concurrent engineering aspects of, most land planning, engineering, farming, geologic, hydrologic, and oceanographic operations.

The curriculum is as follows:

Term 5
Agricultural Engineering 222, Engineering Surveys*
IIA651, Field Astronomy
IIA661, Photogrammetry I
IOR260, Introductory Engineering Probability†
Fluid Mechanics
Liberal studies elective

Term 6
IIA641, Land Surveys
IIA671, Geometrical Geodesy
IID301, Elements of Soil Mechanics
IIA696, Seminar in Remote Sensing
Engineering core science elective
Liberal studies elective

Term 7
IIA656, Geometric Data Adjustment
IIA687, Aerial Photographic Interpretation
Agricultural Engineering 791, Transportation Engineering
Free elective
Liberal studies elective

Term 8
IIE301, Environmental Quality Engineering
Civil and environmental engineering elective
Survey engineering elective
Free elective
Liberal studies elective

*221, Plane Surveying, normally is taken during the sophomore year.
†If previously taken in fulfillment of Basic Studies requirements, a suitable substitution may be made.

Survey engineering electives are:
Military Science 221, Mapping: Theory and Practice
IIA689, Remote Sensing of Earth Resources
IIA662, Analytic Aerotriangulation
IIA685, Physical Environment Evaluation

The extent to which completion of this course of study may or may not meet the requirements of various states for licensure as a Professional Land Surveyor should be discussed with a member of the sponsoring faculty.

Computer Science

(Colleges of Engineering and of Arts and Sciences)

Upson Hall

Degrees Offered: Master of Science, Doctor of Philosophy.

G. Salton, chairman; G. Andrews, A. Borodin, R. L. Constable, R. W. Conway, A. Demers, J. E. Dennis, Jr., J. Donahue, D. Gries, S. P. Han, J. Hartmanis, J. E. Hopcroft, S. S. Owicki, R. Teitelbaum, J. H. Williams.

Courses of instruction are listed on pp. 89–92.

Computer science is a relatively new field of study that draws on and contributes to a number of other disciplines such as mathematics, engineering, linguistics, and psychology. Developments in this field are also useful in research, development, design, and management activities in the various functional areas of engineering and applied science.

At Cornell, computer science is concerned with fundamental knowledge in automata, computability, programming languages, and systems programming, as well as with subjects (such as numerical analysis and information processing) which underlie broad areas of computer applications. Because of the wide implications of research in the field, the Department of Computer Science is organized as an intercollege department in the College of Arts and Sciences and the College of Engineering.

Computing Facilities

The principal computing facility at Cornell is an IBM 370/168, located in Langmuir Laboratory at the Cornell Research Park on the periphery of the campus and directly linked to satellite computers at five different campus locations. The College of Engineering is served through one of these satellite stations in Upson Hall, as well as by a number of teletypewriter terminals in different locations. There are more than a score of other computer installations on campus, ranging up to a PDP-11. These are special-purpose installations and access is usually restricted.

The Degree Programs

The Undergraduate College Program

Although the Department teaches a comprehensive set of undergraduate courses, there is no undergraduate field program in computer science in the College of Engineering. To major in computer science the student may utilize the College Program leading to the degree of Bachelor of Science (see p. 39, for a description of a typical College Program in Computer Science). Each program must be approved after formulation by the student and cannot be specified in an approved form in advance; students interested in a computer science major should consult with a computer science faculty adviser who will help in formulating the appropriate College Program.

Master of Science and Doctor of Philosophy

In the Field of Computer Science, qualified graduate students can earn Master of Science and Doctor of Philosophy degrees.

Graduate students who are interested in the theory, design, and use of automatic computing equipment as a subject in itself should consider the opportunities for advanced training in computer science. In general, they are expected to have a strong background in mathematics, science, or engineering, although students with exceptional records from other fields will also be considered for admission. Students with an interest in the application of computers to their own major fields should consider a graduate minor in computer science to supplement their major field of study. Opportunities for research and study exist in the following areas of computer science: numerical analysis; programming languages and systems; automata and computability theory; information organization and retrieval; and analysis of algorithms.

The program for the M.S. degree involves one year of graduate-level course work and the writing of a thesis. Before the degree is awarded, a candidate must pass a comprehensive examination covering the course work and the thesis.

A Ph.D. program usually involves approximately two years of graduate-level course work, the demonstration of ability to read scientific literature in one foreign language (usually French, German, or Russian), the passing of a comprehensive oral examination, the writing of a dissertation, and a final oral examination on the dissertation. The dissertation must demonstrate the ability of the candidate to conduct an original and independent investigation of high quality and to present the results of the research in a well-organized and cogent manner.

It is possible to obtain the Ph.D. degree without first receiving the M.S. degree, or to obtain the M.S. only. Further information about the Department's teaching and research activities is summarized in an Announcement titled *Graduate Study in Engineering and Applied Science* (see p. 4 for the address). Prospective candidates may communicate with the Graduate Faculty Representative (Computer Science), Upson Hall.

Electrical Engineering

Phillips Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Electrical), Master of Science, Doctor of Philosophy.

G. C. Dalman, director; J. L. Rosson, associate director; P. D. Ankrum, J. M. Ballantyne, T. Berger, H. D. Block, R. Bolgiano, Jr., N. H. Bryant, R. R. Capranica, H. J. Carlin, V. W. S. Chan, L. F. Eastman, W. H. Erickson, D. T. Farley, T. L. Fine, J. Frey, M. C. Kelley, M. Kim, W. H. Ku, C. A. Lee, R. L. Liboff, S. Linke, R. A. McFarlane, H. S. McGaughan, P. R. McIsaac, J. A. Nation, B. Nichols, R. E. Osborn, E. Ott, C. Pottle, L.B. Spencer, R. N. Sudan, G. Szentirmai, C. L. Tang, R. J. Thomas, J. S. Thorp, H. C. Torng, N. M. Vrana, C. B. Wharton, G. J. Wolga.

Courses of instruction are listed on pp. 92–101.

Electrical engineering is a very broad field, and the curricula offered by the School of Electrical Engineering at Cornell reflect this diversity. These curricula provide a foundation in important areas such as random, time-variable, linear, and nonlinear systems and circuits; information theory; quantum electronics and plasma physics; power generation and power systems; control systems; space and optical communication; design of switching circuits; digital processing of signals; computer-aided design; microwave propagation; radio physics; digital circuits, integrated circuits, and solid state microwave devices; and bioelectronics.

The curriculum leading to the degree of Bachelor of Science in the Field Program in Electrical Engineering is intended to give an understanding of the meaning and the application of those physical laws that are basic to electrical engineering and, at the same time, to provide for the student the opportunity for as much study in the fields of humanities and social studies as is consistent with the objectives of modern education in the field of engineering. Also offered is an integrated program, requiring one additional year of study beyond the baccalaureate degree, which leads to the professional degree of Master of Engineering (Electrical). Graduate programs leading to the degrees of Master of Science or Doctor of Philosophy, with concentration in various specialty areas, are also available. The undergraduate and graduate programs are discussed more fully below, under the heading The Degree Programs.

In establishing the undergraduate curriculum, the faculty of the School of Electrical Engineering has recognized the enormous scope of electrical engineering today and has concluded that adequate preparation in electrical engineering requires education in three main areas: *Electrophysics, Systems,* and *Laboratory.* The curriculum contains an integrated series of required courses in each of these interrelated areas.

Electrophysics is concerned chiefly with the physical laws that govern the design or application of electrical devices. Modern devices from machines to lasers are based on principles and properties of electric and magnetic fields, interaction of fields and particles, interaction of fields and circuits, fluid flow, kinetic theory, thermodynamics, quantum mechanics, solid state, plasmas, and bioelectronics. In the curriculum, these subjects are treated in significant depth and breadth. Undergraduate students enrolled in the Field Program in Electrical Engineering are required to complete IEE313, IEE314, and IEE411 as a sequence of electrophysics courses.

The *Systems* sequence deals with the laws that govern the interconnection into circuits and systems of devices whose individual behavior is specified, the response of these systems to various inputs, and the design of systems to perform a variety of functions. These systems may be solely electrical or involve transducers; they may contain both linear and nonlinear elements; they may be passive, active, random, lumped, or distributed. The program is designed to develop competence in the general methods of analysis required for such systems, understanding of the physical significance of the solutions, and knowledge of some aspects of the design of systems for power distribution, computation, control, electronic circuits, communications, pattern classification and decision theory, instrumentation, and biological systems. Undergraduate students enrolled in the Field Program in Electrical Engineering are required to complete IEE311, IEE312, and IEE410 as a sequence of courses in the systems area of study.

The *Laboratory* sequence emphasizes the concept that new developments in engineering practice come from a blend of theory and experimentation. Laboratory work in systems and electrophysics includes experiments in electronic circuits, instrumentation, machinery, electromagnetics, microwaves, solid state devices, computer applications, simulation and modeling, deterministic and random signal channels, etc. Each of the third-year laboratory courses involves two laboratory periods each week. Sufficient time and flexibility are provided to allow for individual exploration, and the goal is to enable students to devise their own experiments. Undergraduate students enrolled in the Electrical Engineering Field Program are required to complete IEE315, IEE316, and six additional hours of electrical engineering electives with laboratory.

A pamphlet, *Electrical Engineering at Cornell,* available from the School of Electrical Engineering, Phillips Hall, provides additional guidance for undergraduate electrical engineering students. It gives details on the following suggested areas of concentration within the Field Program (including the Master of Engineering curriculum): bioengineering; computer engineering; control systems; electronic circuit design; information, communications, and decision theory; microwave electronics; plasma physics; power and energy systems; quantum and optical electronics; radio and atmospheric physics; semiconductor devices and applications.

Laboratory and Research Facilities

A wide variety of excellent facilities are available for both undergraduate and graduate students enrolled in the Field Program in Electrical Engineering. Most of the undergraduate and graduate instruction is given in Phillips Hall, a modern building with more than 100,000 square feet of floor space. Facilities include classrooms, offices for faculty and graduate students, conference rooms, machine and electronics shops, minicomputer facilities, and a variety of laboratories. Each of two undergraduate laboratories is served by a stockroom containing modern electrical and electronic equipment and related instruments needed to implement the laboratory sequence of courses. A number of electrical engineering laboratories are devoted solely to graduate studies and research programs. Among these are laboratories for research in systems and networks, including control systems, analog computers, and switching circuits; microwave electronics; bioelectronics; semiconductor and integrated circuit laboratories, including a modern clean room; quantum and optical electronics, including high power lasers; plasma and gas discharge phenomena; and high-energy pulse power. The internationally known National Astronomy and Ionosphere Center in Arecibo, Puerto Rico, employing a 1,000 foot diameter radio wave reflector, is used for research studies of the upper atmosphere and for research in radio astronomy and radar astronomy.

The Degree Programs

Bachelor of Science

Entry into the Field of Electrical Engineering comes after completion of the first two undergraduate years in the Division of Basic Studies. The upperclass program of study is outlined below.

Term 5	*Credits*
IEE311, Analysis of Electrical Systems I	4
IEE313, Electromagnetic Fields and Waves	4
IEE315, Electrical Laboratory I	4
Liberal studies elective	3
Technical or free elective*	3
Term 6	
IEE312, Analysis of Electrical Systems II	4
IEE314, Electromagnetic Fields and Waves	4

IEE316, Electrical Laboratory II	4
Liberal studies elective	3
Technical or free elective*	3

Term 7

IEE410, Random Signals in Systems†	4
IEE411, Quantum Theory and Applications†	4
E. E. elective with laboratory	3 or 4
Liberal studies elective	3
Technical or free elective*	3

Term 8

E. E. elective with Laboratory	3 or 4
E. E. elective††	3 or 4
E. E. elective††	3 or 4
Liberal studies elective	3
Technical or free elective*	3

*During enrollment in the Electrical Engineering Field Program, a student must satisfactorily complete two technical and two free electives. The order in which these elective requirements are fulfilled is the student's choice.

†Upon petition to the Faculty Committee, a student may be allowed to substitute an appropriate technical course for one of these required courses.

††Students having special career goals may propose appropriate technical or professional electives to substitute for the electrical engineering electives. The approval of the adviser is required for such substitutions.

A wide selection of elective courses in the Field of Electrical Engineering is available to four-year students. The field electives are listed below.

Theory of Systems and Networks

IEE620, Bioelectric Systems
IEE621, Introduction to Biomechanics, Bioengineering, Bionics, and Robots
IEE623, Active and Digital Network Design
IEE624, Computer Methods in Electrical Engineering
IEE625, Computer Aided Network Design
IEE627, Fundamentals of Linear Networks
IEE628, Network Theory and Applications
IEE721, Theory of Linear Systems
IEE722, Theory of Nonlinear Systems

Electronics

IEE430, Introduction to Lasers and Optical Electronics
IEE432, Solid State Physics and Applications
IEE531, Electronic Circuit Design I
IEE532, Electronic Circuit Design II
IEE631, Semiconductor Electronics I
IEE632, Semiconductor Electronics II
IEE633, Solid State Microwave Devices and Subsystems I
IEE634, Solid State Microwave Devices and Subsystems II
IEE635, Integrated Circuit Technology
IEE636, Circuit Design for Integration
IEE731, Quantum Electronics I
IEE732, Quantum Electronics II
IEE733, Opto-Electronic Devices
IEE734, Nonlinear Optics
IEE735, Solid State Devices I
IEE736, Solid State Devices II
IEE737, The Physics of Solid State Devices I
IEE738, The Physics of Solid State Devices II

Power Systems and Machinery

IEE551, Contemporary Electrical Machinery I
IEE552, Contemporary Electrical Machinery II
IEE651, Electric Energy Systems I
IEE652, Electric Energy Systems II

Communications, Information, and Decision Theory

IEE661, Coding Algorithms
IEE662, Fundamental Information Theory
IEE663, Statistical Aspects of Communication
IEE664, Decision Making in Pattern Classification
IEE761, Random Processes in Electrical Systems I
IEE762, Random Processes in Electrical Systems II
IEE763, Advanced Information Theory
IEE764, Foundations of Inference and Decision Making

Computing Systems and Control

IEE671, Feedback Control Systems I
IEE672, Feedback Control Systems II
IEE674, Analog-Hybrid Computation
IEE675, Switching Circuits and Logic Design
IEE676, Computer Structures
IEE677, Computer Architecture and Design I
IEE678, Computer Architecture and Design II
IEE771, Estimation and Control in Discrete Linear Systems
IEE772, Optimal Control and Estimation for Continuous Systems
IEE773, Random Processes in Control Systems

Radio and Plasma Physics and Electromagnetic Theory

IEE410, Thermal and Statistical Physics for Engineers
IEE581, Wave Phenomena in the Atmosphere
IEE582, Radio Engineering
IEE680, Elementary Plasma Physics and Gas Discharges
IEE681, Introduction to Plasma Physics
IEE682, Advanced Plasma Physics
IEE683, Electrodynamics
IEE684, Microwave Theory
IEE685, Upper Atmosphere Physics I
IEE686, Upper Atmosphere Physics II
IEE687, Radiowave Propagation I
IEE688, Radiowave Propagation II
IEE781, Kinetic Theory
IEE782, Nonlinear Phenomena in Plasma Physics

The scholastic requirement for electrical engineering students is a minimum grade-point average of 1.8 in third-and fourth-year courses. A student failing to make satisfactory progress toward a degree, as evidenced by a low average, by course failures, or by low grades in major courses, may be allowed an additional term in which to meet the scholastic requirements, or may be suspended from the School.

Master of Engineering (Electrical)

The purpose of this degree program is to offer depth of study in both comprehensive and specialized electrical engineering subjects and to offer material which can extend the abilities of the electrical engineer to other fields.

The general requirements for the degree are given on p. 13. Specific requirements for the M.Eng. (Electrical) degree include a minimum of four courses in advanced electrical engineering, consisting of two approved pairs chosen from a designated list on file with the M.Eng. (Electrical) adviser.

The required engineering design project is accomplished on an individual basis, and a formal report must be submitted. Design projects are often sponsored by industry or governmental agencies. Recent projects have included the design of an electric automobile, a radio deer-tracking system for conservation purposes, electronic instrumentation for blood testing, millimeter-wave detectors, and a remotely controlled vehicle for exploring planetary surfaces.

There are no residence requirements, although all course work must, in general, be completed under Cornell University staff instruction. The degree requirements must normally be completed within a period of four calendar years. A minimum grade-point average of 2.5 must be maintained.

Master of Science and Doctor of Philosophy

The requirements for the degree of Master of Science and Doctor of Philosophy are described in the *Announcement of the Graduate School.* These are research degrees that involve residence on the campus and submission of a thesis.

In the School of Electrical Engineering, research work leading to these degrees may be undertaken in the area of *electrophysics* including radio propagation, radio and radar astronomy, electromagnetics, plasma physics, physical and microwave electronics, microwave solid state devices, integrated circuits, materials science and solid state physics in electrical engineering, quantum electronics and laser optics, biomedical electronics, electric power conversion, electrical breakdown phenomena, etc., or in the area of *systems* including information and decision theory, network theory, power and energy systems, communications systems, control systems, switching circuits, digital networks, computers and computer-aided design, cognitive systems, etc. A number of fellowships, research assistantships, and teaching assistantships are available to candidates for the M.S. and Ph.D. degrees who are doing their thesis research in the School of Electrical Engineering.

A description of the feld and some of the research projects now being conducted at the school is included in a special Announcement. *Graduate Study in Engineering and Applied Science*(see p. 4).

Further information may be obtained from the Graduate Faculty Representative (Electrical Engineering), Phillips Hall.

Environmental Engineering

See p. 34.

Geological Sciences

(Colleges of Engineering and of Arts and Sciences)

Kimball Hall

Degrees Offered: Bachelor of Science, Master of Science, Doctor of Philosophy.

J. E. Oliver, chairman; J. M. Bird, A. L. Bloom, B. Bonnichsen, J. L. Cisne, B. L. Isacks, D. E. Karig, S. Kaufman, G. A. Kiersch, W. B. Travers, D. L. Turcotte.

Courses of instruction are listed on pp. 101–104.

Study in geological sciences is offered for students who are preparing for careers in solid earth science, for those who want a broad background in the geological sciences as preparation for careers in other fields, or for those who wish to combine geological training with other sciences such as agronomy, astronomy and space science, biological sciences, chemistry, economics, mathematics, physics, or various fields of engineering. The organization of the Department of Geological Sciences as an intercollege department in the College of Arts and Sciences and the College of Engineering facilitates the structuring of individualized programs of study.

At the graduate level, interdisciplinary programs lead to the Master of Science and Doctor of Philosophy degrees in geological sciences. The Department maintains a number of strong research programs, with the new theory of plate tectonics serving as the common focus for many of them.

Geological sciences may be chosen as a study program in a professional engineering field (see Master of Engineering degree program, p. 13).

The Department recommends that its students have strong preparation in mathematics and the basic sciences or engineering; for students with such training, transfer to geological sciences at any level is encouraged. The curriculum is designed to accommodate students who have no introductory education in geology but are otherwise well qualified.

Laboratory and Research Facilities

The outlook of the Department is global in scope, and its activities are widespread.

A network of seismographs and related instruments is operated in the Tonga-Fiji-New Hebrides area of the

South Pacific, and there is a seismograph station on the Ithaca campus. An extensive microfilm collection of records of the World Wide Network of Standardized Seismographs is available for studies of earthquakes throughout the world. Two 24-channel reflection seismographs, gravimeters, magnetometers, and other geophysical instrumentation are available.

Investigations in marine geology may be pursued aboard research vessels or at a marine laboratory operated by Cornell at the Isles of Shoals off the New Hampshire coast.

Research in structural geology, tectonics, sedimentation, petrology, engineering geology, mineral deposits, and areal and regional geology is carried out at a variety of field sites. The list includes Indonesia, Taiwan, islands of the South Pacific, British Columbia, Oregon, the Snake River Plain, the Duluth Complex, Newfoundland, and the Caribbean. A program of deep seismic reflection profiling involves sites throughout the United States.

The Ithaca region is particularly suited for research in stratigraphy, paleontology, geomorphology, and glacial geology, and the nearby Adirondack area, where Cornell has a field camp, is a classic one for studies in metamorphic and igneous petrology.

At Cornell the Department maintains well-equipped geological sciences laboratories, which are augmented by special advanced equipment available in other parts of the University. Exceptionally good collections of minerals, ores, fossils, and recent mollusks are on hand. Facilities are also available to the specialized investigator at the Paleontological Research Institution, a private organization, located near the campus.

The Degree Programs

Bachelor of Science

In the College of Engineering, students interested in entering the Field Program in Geological Sciences follow the Basic Studies Program for the first two years. It is recommended that Geology IGE101 and IGE102, Chemistry 208, and for those students interested in geobiology, Biological Sciences 101–102 and 103–104 be taken as electives during this period.

Students in the Field Program in Geological Sciences are required to complete the following, or their equivalents: (1) the six core courses in Geological Sciences: IGE325, IGE345, IGE355, IGE356, IGE376, and IGE388; (2) an acceptable summer field course, or the equivalent; and (3) four approved advanced courses in physics, chemistry, biology, engineering, or mathematics. Programs during the third and fourth years are as follows:

Term 5	*Credits*
Geological Sciences IGE355	4
Geological Sciences IGE376	4
Required science course	3 or 4
Liberal elective	3
Technical or free elective	3 or 4
Term 6	
Geological Sciences IGE356	4
Geological Sciences IGE325	4
Required science course	3 or 4
Liberal elective	3
Geological Sciences IGE704	6
or	
Technical or free elective	3 or 4

A summer field course is required unless approval for an alternative field experience is granted.

Term 7	
Geological Sciences IGE345	4
Required science course	3 or 4
Liberal elective	3
Technical or free elective	3 or 4
Term 8	
Geological Sciences IGE388	4
Required science course	3 or 4
Liberal elective	3
Technical or free elective	3 or 4
Free elective	3 or 4

Students intending to specialize in *geophysics* should select their *required sciences* from the following courses or their equivalents: Mathematics 421–422–423, Applicable Mathematics; IAA350–351, Advanced Engineering Analysis I and II; IP355, Intermediate Electromagnetism; IP333, Mechanics of Particles and Solid Bodies; IP456, Intermediate Electrodynamics; IP434, Continuum Physics; Physics 410, Advanced Experimental Physics; IAB610, Introduction to Continuum Mechanics.

Students intending to specialize in *geochemistry* (including petrology, mineralogy, and mineral deposits) should select their *required sciences* from the following courses or their equivalents: Chemistry 300, Introductory Quantitative Analysis; Chemistry 301, Experimental Chemistry I; Chemistry 302, Experimental Chemistry II; Chemistry 303, Experimental Chemistry III; Chemistry 357–358, Introductory Organic Chemistry; Chemistry 389–390, Physical Chemistry I and II; Chemistry 410, Inorganic Chemistry; ITK311, Structure and Properties of Materials; ITK335, Thermodynamics of Condensed Systems.

Students intending to specialize in *geobiology* should select their *required sciences* from the following courses or their equivalents: Biological Sciences 316, Invertebrate Zoology; Biological Sciences 431–432, Principles of Biochemistry; Biological Sciences 145, Plant Biology; Biological Sciences 448, Plants and Time (Paleobotany); Biological Sciences 361, General Ecology; Biological Sciences 373, The Vertebrates; Biological Sciences 476, Organic Evolution; Biological Sciences 281, Genetics; Chemistry 253, Elementary Organic Chemistry; IGE471, Invertebrate Paleontology.

Students who wish to pursue further training or immediate employment in *applied geology* (environmental/engineering geology, mineral exploration and exploitation, ground water, petroleum geology, or geological engineering) should select their *required sciences* from the following courses or their equivalents, with two of four from the same field: Agronomy 301, Identification, Appraisal and Geography of Soils; Agronomy 701, Soil Chemistry; Agronomy 607, Soil Physics; IID301, Elements of Soil

Mechanics; IID610, Engineering Properties of Soils; IIA685, Physical Environment Evaluation; ITE331, Structure and Properties of Materials; ITE446, Mechanical Properties of Materials; IIC301, Fluid Mechanics; IIC302, Hydraulic Engineering; IIE301, Environmental Quality Engineering; Mathematics 421–422–423, Applicable Mathematics; IOR260, Introductory Engineering Probability; IOR370, Introduction to Statistical Theory with Engineering Applications.

Students who want a more general background, or who wish to remain uncommitted with regard to specialty, must choose at least two of the four required science courses from the same field, and all four required science courses must be at the 300 level or above.

A total of four liberal electives are normally taken during terms 5, 6, 7, and 8, in addition to two technical electives and two free electives. The technical electives may be chosen from offerings in geological sciences or in other science or engineering fields, and may be courses also approved as required sciences.

Students intending to pursue graduate study in geology are reminded that many graduate schools require proficiency in reading the scientific literature in one or two of the three languages French, German, or Russian. Undergraduate preparation in at least one of these languages is therefore advantageous.

Outstanding students in this program may request substitution of an honors thesis for a fourth-year technical elective.

College Program. Students who wish to follow a program of study in geological sciences substantially different from those outlined above may do so under the College Program. Such students should consult with the appropriate faculty members as early as possible. A description of the College Program is given on p. 38.

Master of Science and Doctor of Philosophy

The program of graduate study in the Field of Geological Sciences is designed to give broad training in both the field and the laboratory.

A major subject may be selected from the following: economic geology; engineering geology; environmental geology; geobiology; paleontology and stratigraphy; geochemistry, mineralogy, petrology; geomorphology; geophysics; geotectonics and structural geology; marine geology; physical geography; and seismology.

Minor subjects are selected from those listed above, or from Pleistocene geology, hydrogeology, sedimentation, and oceanography, or from other areas such as agronomy, botany, engineering, chemistry, mathematics, physics, materials science, water resources, zoology, the biological sciences, or certain nonscientific fields. Ph.D. degree candidates select at least one minor subject outside the Field. Cooperative graduate programs in many interdisciplinary areas are available.

Detailed information about the M.S. and Ph.D. programs is given in the *Announcement of the Graduate School,* and a description of graduate study opportunities in geological sciences is included in the Announcement, *Graduate Study in Engineering and Applied Science* (see p. 4). Further information may be obtained by writing to the Graduate Faculty Representative (Geological Sciences), Kimball Hall.

Industrial Engineering and Operations Research

Upson Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Industrial). The programs in this field are administered by the School of Industrial Engineering and Operations Research. The graduate Field of Operations Research offers the Master of Science and Doctor of Philosophy degrees; see p. 62.

B. W. Saunders, director; R. N. Allen, R. E. Bechhofer, L. J. Billera, E. K. Clemons, D. R. Fulkerson, D. C. Heath, W. F. Lucas, W. L. Maxwell, J. A. Mucrstadt, G. L. Nemhauser, N. U. Prabhu, M. W. Sampson, T. J. Santner, A. Schultz, Jr., M. S. Taqqu, H. M. Taylor 3d, M. J. Todd, L. E. Trotter, Jr., B. W. Turnbull, L. I. Weiss.

Courses of instruction are listed on pp. 104–109.

Industrial engineering and operations research, the most rapidly growing field of engineering today, offers opportunities for work in a broad range of activities involving integrated systems of people, materials, and equipment.

Industrial engineering is defined as the design, improvement, and installation of such systems; the principles and methods of engineering analysis and design are used to specify, predict, and evaluate the results to be obtained from them. Operations research is concerned with the underlying science of operational phenomena, and since all systems are operational, this discipline is closely related to industrial engineering.

The scope and methods of industrial engineering have expanded greatly in recent years, in response to new and increased needs of public and private organizations and the availability of new tools and skills. Twenty years ago, nearly all industrial engineering was practiced in the manufacturing phase of the mechanical goods industries, but today the work of industrial engineers extends to a very broad range of systems problems and areas.

As a result, the Cornell program in industrial engineering and operations research is ideal for those preparing to be systems engineers, regardless of the type of system of interest. By proper choice of electives and technological sequences, a student enrolled in the Field Program in Industrial Engineering and Operations Research can plan a program to emphasize industrial systems, information systems, transportation systems, communication systems, health-care systems, or some combination of these. If a student prefers to prepare for a career in research in the underlying science and methodology on which modern systems engineers depend, a program can be arranged to include more courses in mathematics and operations research.

Many students entering the field are unsure of their career goals or are unfamiliar with the multitude of opportunities available.The curriculum has been planned with this in mind. The scientific basis and methodology that underlie applications in all fields are emphasized, rather than any particular technological orientation. For those students who do have well-defined goals, ample elective choices are provided so that they can begin the process of specialization.

Because of the flexibility and diversity of the program, it appeals to a broad range of students and leads to an even broader range of career opportunities. Graduates are employed by manufacturing and service industries, by public and private research organizations, and by private consulting firms. They are working not only with industrial systems, but also in such areas as transportation, distribution, urban studies, military logistics, weapons-systems analysis, retailing, finance, and public health.

Laboratory and Research Facilities

The School of Industrial Engineering and Operations Research is housed in Upson Hall, where available facilities include a remote terminal of the University's control computer. The school is one of the principal users of the University's Computing Center, which constitutes a basic laboratory for students of industrial engineering and operations research. Computer-based work is especially important in upperclass courses and in graduate research. Many research problems and projects in engineering design are supplied by industrial plants located in the area, by University operations, and by community activities.

The Degree Programs

Bachelor of Science

The first two years of undergraduate study are administered by the Division of Basic Studies. Students may enter the School of Industrial Engineering and Operations Research in the junior year.

During the sophomore year, a student who plans to major in industrial engineering and operations research must elect, as one of the four engineering core sciences, Introductory Engineering Probability IOA260. If a second core science from the mathematics group is desired, IOA213 would be an excellent choice, although it is not required. Another good choice might be Computer Science ICS211, since it is required in the fifth term of the IE/OR program if it has not been taken during the sophomore year. Other core science choices would depend on the goals of the individual student. If, for instance, a student wished to concentrate later studies in some branch of electrical systems, he or she should include IEE210 among the core sciences. If a student's interests were directed toward manufacturing systems, then IAK221 should be included. Proper choices at the sophomore level will enhance considerably the elective choices that can be made during the fourth and fifth years. Early consultation with an IE/OR faculty member or with the director can be especially helpful in making appropriate choices. In the junior year (the first in the field), the following program of courses is required so that the student will be prepared for the options that are available in the fourth year.

Term 5	*Credits*
IOR320, Optimization Methods I	4
IOR350, Cost Accounting, Analysis, and Control	4
IOR370, Introduction to Statistical Theory with Engineering Applications	4
ICS211, Computers and Programming*	3
Liberal studies elective	3
Term 6	
IOR321, Optimization Methods II	3
IOR361, Probabilistic Models in IE/OR	4
IOR383, Applications of Computer Science in IE/OR	4
Behavorial science†	3
Liberal studies elective	3

*If ICS211 is completed during the sophomore year, an appropriate three credit hour technical elective may be substituted by agreement with the IE/OR adviser.

†The behavioral science requirement can be satisfied by any one of several courses of an advanced nature. Possible courses include Business and Public Administration NBB520, NBB521, or NBF602. Industrial and Labor Relations 121 also covers many of the necessary topics. For those contemplating the pursuit of a graduate business degree, NBB520 is recommended. The adviser must approve the selection in all cases.

The Fourth Year Flexibility. Because modern industrial engineering and operations research covers such a wide spectrum of interests, and because students approaching their fourth year of study have begun to identify their particular interests, optional sequences covering the major areas of specialization are offered for the senior year program. Each student must select two two-course sequences from an approved list. At least one of these sequences must be in IE/OR; the second may be in some other technological area. This option is designed to accommodate the needs of students who intend to apply their systems methodology in a field other than IE/OR.

In addition, one technical elective, one liberal studies elective, and one free elective are chosen each term. The technical electives can be selected from the optional sequences, or can be additional mathematical courses or appropriate technological courses. The free electives can be selected from the offerings of any division of the University. Because of the flexibility that this program offers, it is imperative that electives be chosen carefully. The director of the School should be consulted early by each student to ensure that the student's objectives can be realized. Many students, for instance, elect to seek a master's degree from the Graduate School of Business and Public Administration, an option that is facilitated by early planning. De-

tails of the arrangements that are possible for a combined engineering and business program are discussed below under Cooperative Program with Business and Public Administration.

The basic curriculum for the fourth year, from which individualized programs are developed, comprises the following courses:

	Credits
Four courses consisting of two two-course sequences as described below	minimum of 12
Two technical electives (these need not be sequential)	6
Two liberal studies electives	6
Two free electives	6

Available IE/OR sequences are as follows:

	Credits
Industrial systems: IOR410 and IOR421*	8
Information systems: ICS410 and IOR682	8
Optimization methods: IOR437 and IOR435	8
Applied statistics: IOR471 and IOR570	7

*This sequence must be selected by students who plan to participate in the cooperative program with the Graduate School of Business and Public Administration

Students who have established specific career goals and wish to apply the IE/OR methodology in other technological areas, such as mechanical engineering, manufacturing processing, environmental engineering, public systems, health-care systems, or urban systems, may substitute a course sequence appropriate to the outside discipline for one of the required IE/OR sequences. Examples of possible sequences outside IE/OR are:

	Credits
Manufacturing systems: IMM311 and IMM612	6
Transportation systems: IIF621 and IIF624	7
Public systems: IIF614 and IIF618	6
Electrical systems: IEE311 and IEE312	8
Numerical methods: ICS321 and ICS322	8

Other sequences are possible and should be checked with the student's adviser.

These options, together with an appropriate choice of technical electives, enable a student to earn at least twelve credit hours in a technological field other than IE/OR. Through an appropriate choice of free electives also, as many as eighteen credit hours can be earned in the secondary discipline.

The IE/OR program is designed to provide a rigorous basic analytical methodology and yet be flexible enough to accommodate individual goals. Early and frequent consultation with a faculty adviser is necessary if a good fourth year program is to be achieved.

College Program. Some students prefer to emphasize one particular facet of industrial engineering and operations research, such as statistics, probability, or mathematical programming, and combine this with studies in another area, such as biology, computer science, mathematics, mathematical economics, econometrics, or chemical or environmental engineering. Such diversity can be achieved through a College Program (see p. 38), which permits the student to choose a major and a minor field of study in a completely planned upperclass curriculum. It should be noted, however, that such objectives can usually be met within the flexibile IE/OR Field Program.

Academic Requirements. Scholastic requirements for the field are a passing grade in every course, maintenance of a grade-point average of at least 2.0, and satisfactory progress toward completion of the degree requirements. The student's performance is reviewed at the conclusion of each term.

Graduate Programs in IE/OR

At the conclusion of the four-year program, students who wish to continue their studies in the broad field of industrial and systems engineering or in operations research may apply for one of two graduate programs available at Cornell. One, offered by the graduate Field of Operations Research, emphasizes research and basic theoretical content and leads to the Master of Science or Doctor of Philosophy degree (see pp. 62–64). The other program, intended for those students who are interested in applied operations research or systems engineering—whether in industry, government, or the service sectors—leads to the professional degree of Master of Engineering (Industrial).

Master of Engineering (Industrial)

This one-year professional degree program is application-oriented rather than research-oriented, and requires completion of a project. The course work centers on additional study of analytical techniques, with particular emphasis on engineering applications, especially in the design of new or improved man-machine systems, information systems, and control systems.

This program is integrated with the Cornell undergraduate degree program in industrial engineering and operations research, and students who apply during their senior year will generally be admitted if their past performance indicates the ability to do graduate work. Since there is some interchangeability in the applications courses available during the fourth and fifth years, careful planning of the work is needed and early consultation with an adviser is recommended.

Requests for admission from Cornell undergraduates in engineering programs other than the IE/OR Field Program are welcome. Also considered are non-Cornellians who hold a baccalaureate degree in a field of engineering from an institution of recognized standing, have adequate preparation for graduate study in industrial engineering, and show promise of doing well in advanced study. Students from these groups may need to follow a slightly different curriculum than the one planned for Cornell IE/OR undergraduates. To assure completion of the program in one calendar year, the entering student should have completed courses in probability theory and basic probabilistic models and in computer programming, and should have acquired some fundamental knowledge of economic concepts required for decision making. Students who do not have these prerequisites must be prepared to take at least three semesters of course work to qualify for the degree. The two parallel course programs leading to the Master of Engineering (Industrial) degree are outlined below.

I. For matriculants with preparation comparable to that provided by the undergraduate Field Program in IE/OR:

Fall term	*Credits*
IOR516, Mathematical Models	4
IOR680, Digital Systems Simulation	4
IOR898, Project Laboratory	1
IOR893, Seminar	1
Depth elective	minimum of 3
Breadth elective	minimum of 3
Spring term	
IOR551, Advanced Economic Analysis	4
IOR899, Project Work	minimum of 4
IOR894, Seminar	1
Depth elective	minimum of 3
Breadth elective	minimum of 3

The electives specified above will normally be chosen from graduate courses offered by the Department of Operations Research. The depth elective will generally continue study in one of the topics elected to satisfy one of the fourth-year sequence requirements. The breadth elective will generally be one of these sequences available in the fourth year (see listing under Bachelor of Science) but not selected by the student for the undergraduate curriculum.

II. For matriculants from other major fields of engineering who fulfill the basic prerequisite requirements but do not qualify for Program I:

Fall term	*Credits*
IOR670, Statistics	4
IOR622, Operations Research I	3
IOR516, Mathematical Models	4
IOR893, Seminar	1
IOR898, Project Laboratory	1
Professional elective	minimum of 3
Spring term	
IOR383, Applications of Computer Science	4
IOR623, Operations Research II	3
IOR551, Economic Analysis	4
IOR794, Seminar	1
IOR899, Project Work*	minimum of 4
Professional elective	minimum of 3

*In many cases it will be preferable to delay IOR899 until the completion of the spring-term course work. The project requirements could be completed during the following summer, and the degree conferred in September.

The project work required for the degree of Master of Engineering corresponds to the thesis required in many Master of Science degree programs. The M.Eng. (Industrial) student fulfills the project requirement (IOR898-899) by working individually or as part of a group of no more than four students on an operational systems problem that actually exists in some organization. Frequently, students encounter appropriate problems in summer work with a sponsoring organization. Alternatively, projects may be selected by the faculty from a reservoir of appropriate problems submitted by various operating organizations such as manufacturing firms, retailing organizations, service organizations, governmental agencies, and educational institutions.

Cooperative Program with Business and Public Administration

Of the three degree programs offered by the School of Business and Public Administration at Cornell, the Master of Business Administration program is of most interest to engineers. Because modern management is concerned with the operations of production and service systems, much of the analytical methodology that is required to deal with operating decisions is the same methodology that systems engineers must use in designing the systems. Therefore, there are several subjects required in the M.B.A. program which IE/OR students take as undergraduates. A recent agreement between the School of Industrial Engineering and Operations Research and the Graduate School of Business and Public Administration recognizes this fact and provides an unusual opportunity for the IE/OR undergraduate. Through proper elective choices, the M.B.A. program can be completed in one additional year following completion of the M.Eng. degree requirements.

Essential points of the agreement (which takes precedence over other descriptions of the M.B.A. requirements) are:

1. That the IE/OR candidate have completed by course work, advanced standing, or exemption examinations, the core course work required for the M.B.A. degree, except for Business Policy, by the end of the fifth year.

2. That thirty hours, at most, of advanced standing will be awarded by Business and Public Administration for work done before the start of the sixth year in the undergraduate B.S. program, in the M.Eng. program, and in Business and Public Administration.

3. That during the sixth year, over a period of two semesters, the candidate will complete twenty-six elective hours approved by Business and Public Administration, plus Business Policy (four credit hours).

The candidate would qualify for the B.S. degree at the end of four years, the M.Eng. degree at the end of five years, and the M.B.A. degree at the end of six years.

Further details and applications forms for this special program may be obtained from the office of the School of Industrial Engineering and Operations Research, Upson Hall.

Materials Science and Engineering

Bard Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Materials), Master of Science, Doctor of Philosophy.

R. W. Balluffi, director; D. G. Ast, J. M. Blakely, M. S. Burton, L. DeJonghe, H. H. Johnson, C.-Y. Li, R. Raj, E. J. Kramer, D. L. Kohlstedt, A. L. Ruoff, S. L. Sass, D. N. Seidman.

Courses of instruction are listed on pp. 109–112.

In all areas of modern technology, advances in system efficiency and economy are often limited by the properties of the materials that are available to the engineer. Engineering materials include such diverse substances as metals, semiconductors, ceramics, polymers, glasses, and combinations of these. Significant technological breakthroughs in diverse fields such as structures, power, communications, propulsion, chemical processing, or transportation frequently are a direct result of improvements in materials—either the development of new materials or the evolutionary improvement of existing ones.

As the field exists today, it is perhaps best described as a fusion of the traditional interests of the metallurgist with the basic understanding and wide scientific interest of the solid state physicist and chemist. The distinguishing "theme" of this field is the relation between the structure of materials and their properties. The structure of solids encompasses such specific aspects as crystalline structure and imperfections, molecular arrangement, phase composition and morphology, and grain size. These and other characteristics from the atomic to the macroscopic scale control the behavior of a material. Materials science is concerned with the understanding of these characteristics and with methods of influencing them, and materials engineering deals with applications, particularly with the selection, processing, characterization, and testing of materials.

Laboratory and Research Facilities

The department of Materials Science and Engineering is centered in Bard Hall and occupies parts of Thurston and Kimball Halls, a total area of 50,000 square feet. Bard Hall, the newest of the Cornell engineering buildings, was completed in 1963. It is extensively equipped for both undergraduate and graduate instruction and research. Facilities for characterizing and studying the structure of solids by physical measurement, microscopy, metallography, and X-ray diffraction are available. Included is equipment for processing materials by casting, welding, heat treatment, compacting and sintering, deformation, and many of the newer processing procedures such as crystal growth and deposition from the vapor phase. Laboratories for preparing and studying non-metallic materials, especially ceramics, are also housed in Bard Hall.

This Department participates with other departments of the University in the interdisciplinary Materials Science Center. The Center supports central facilities in Bard, Thurston, and Clark Halls for service and research in metallography, X-ray diffraction, electron microsopy, mechanical testing, and effects of high temperature and high pressure on materials. The Materials Science Center also supports service facilities for producing, characterizing, and testing various metallic and nonmetallic materials.

The Degree Programs

Bachelor of Science

The upperclass curriculum in materials science and engineering builds upon the engineering science, physics, mathematics, and chemistry courses of the Division of Basic Studies. The Department does not require any particular engineering science course in the sophomore year as a prerequisite for entry into the upperclass program.

The courses which comprise the Field Program are supplemented by the two technical electives, two free electives, and four liberal studies electives that are required for all upperclass students in the College. Students are therefore able to incorporate a wide variety of scientific and engineering studies into their curricula. The field courses need not be taken according to a rigid pattern. Various combinations and sequences are possible, depending to some extent upon the student's particular interests and elective choices in the sophomore year. Faculty advisers of the Department assist each student in planning a suitable program and selecting appropriate elective courses.

Required Field Courses. The required field courses are listed in the following example of a program in materials science and engineering:

Term 5	*Credits*
ITE331, Structure and Properties of Materials	4
ITE335, Thermodynamics of Condensed Systems	3
ITE333, Research Involvement I or a Field-approved technical elective	3
Free elective	3
Liberal studies elective	3
Term 6	
ITE336, Kinetics, Diffusion, and Phase Transformations	3
ITE440, Macro-Processing of Materials	3
ITE334, Research Involvement II or a Field-approved technical elective	3
Free elective	3
Liberal studies elective	3
Term 7	
ITE445, Electrical and Magnetic Properties of Materials	3
ITE441, Micro-Processing of Materials	3
ITE443, Senior Laboratory I*	3
Technical elective	3
Liberal studies elective	3

Term 8

ITE446, Mechanical Properties of Materials	3
ITE448, Current Topics in Materials	3
ITE444, Senior Laboratory II*	3
Technical elective	3
Liberal studies elective	3

*One term of Senior Laboratory may be replaced by Physics 360, Introductory Electronics, or by a one-term project in association with a faculty member.

Features of the Field Program are:

1. The Research Involvement option allows students who may be interested in a research/development career to acquire a first-hand exposure to this kind of activity relatively early in their academic careers. A student with this interest affiliates with a faculty member and his or her research group and works on a problem in the group's general field of investigation. It is necessary that a mutual interest be established between the student and a faculty member.

2. The extra technical elective in the third year provides students interested in pursuing an industrial career after receipt of the B.S. degree an additional opportunity to broaden their engineering education. This is especially important for B.S. graduates in materials science and engineering, since they frequently work in collaboration with graduates of other engineering disciplines.

3. The fourth-year course in Current Topics in Materials is used to acquaint students with recent developments in new areas such as biomaterials, fuel cells, composite materials, and materials problems associated with nuclear power systems. Student suggestions for desirable topics are sought in advance.

4. The Senior Laboratory courses typically require two to four experiments a term. Each experiment may take several weeks to complete. The emphasis is on student initiative in the design and execution of the experiment, with faculty supervision.

5. The following is a complete list (including those listed under Required Field Courses) of courses available for students with special interests in processing and applications. These courses emphasize practical problems and applications in areas that have growing importance as international competition in technology increases.

ITE447, Applied Metallurgy
ITE333, Research Involvement I
ITE334, Research Involvement II
ITE337, Materials and Manufacturing Proesses
ITE338, Analysis of Manufacturing Processes
ITE440, Macro-Processig of Materials
ITE441, Micro-Processing of Materials
ITE448, Current Topics in Materials

The College Program. For students wishing to combine the study of materials with some other discipline, course sequences are available to provide a major or minor program in materials science and engineering. These will be selected by the student and his or her adviser. (See p. 38 for an outline of the College Program.)

Master of Engineering (Materials)

Students who have completed a four-year undergraduate program in engineering or the physical sciences are eligible for consideration for admission to this program. Students will carry out independent projects that provide experience in defining objectives, planning and carrying through systematic work, and reporting conclusions. In addition, students will have the opportunity to develop further their knowledge and skill in specialized areas of materials science. The program includes the following:

1. A project qualifying for at least twelve hours of credit and requiring individual effort and initiative. This project, carried out under the supervision of a member of the faculty, is usually experimental, although it can be analytical.

2. Six credit hours of courses in mathematics or applied mathematics. This requirement may be satisfied by courses IAA350 and IAA351; students who have previously completed these must select other courses acceptable to the faculty.

3. Courses in materials science and engineering selected from any of those offered at the graduate level, or other courses approved by the faculty, required to bring the total credit hours to thirty.

Master of Science and Doctor of Philosophy

Unique opportunities are open to the student undertaking graduate study in materials at Cornell. Instruction is given in a broad spectrum of topics, ranging from the fundamental aspects of materials behavior to problems associated with materials applications. Studies of metallic and nonmetallic materials, as well as some aspects of the liquid state, are incorporated into a common framework of instruction.

The Master of Science and Doctor of Philosophy programs are primarily science-oriented programs of study directed toward a career in research, development, advanced engineering, or teaching. A candidate for either degree may choose as the major subject area either *materials science* or *materials and metallurgical engineering*. Requirements for these degrees are described in the *Announcement of the Graduate School*.

A student who enters with an undergraduate degree may register for either the M.S. or Ph.D. degree. However, it is possible for a student in the M.S. program to transfer to the Ph.D. program. Toward the end of the first year, the student's progress is reviewed by his or her Special Committee, and if that group takes favorable action then or at a later date, the student is accepted as a Ph.D. candidate.

The courses offered by the field assume a sound undergraduate education in such areas as mathematics, physical metallurgy, atomic and solid state physics, and thermodynamics. Graduate students enrolled with deficiencies in any of these areas will be permitted to take intermediate-level courses, with the understanding that more time may be needed to complete the degree program.

To form an adequate foundation for more specialized courses and for thesis research, the faculty has developed a core program of courses in materials science. These cover modern theories of structure and of materials behavior at an advanced level.

Courses available to graduate students are listed below.

Graduate Course Program:
ITE701, Topics in Thermodynamics and Kinetics
ITE702, Phase Transformation
ITE703, Elasticity and Physical Properties of Crystals
ITE704, Plastic Flow and Fracture of Materials
ITE706, Principles of Diffraction
ITE707, Solid State Physics

Other Graduate Courses:
ITE553–554, Special Project
ITE712, Selected Topics in Diffraction
ITE714, Electron Microscopy
ITE716, The Effects of Radiation on Materials
ITE762, Physics of Solid Surfaces
ITE765, Amorphous and Semi-Crystalline Materials
ITE767, Electrical and Magnetic Properties of Materials
ITE768, Theory of Crystal Defects
ITE769, Ceramic Materials

Materials Processing and Applications:
ITE338, Analysis of Manufacturing Processes
ITE447, Applied Metallurgy
ITE441, Micro-Processing of Materials
ITE448, Current Topics in Materials
ITE553–554, Special Project

A significant part of the Cornell graduate educational experience is the opportunity to participate in formal and informal seminars and research conferences at which current Cornell research programs are described and guest speakers present the latest developments in other laboratories.

An Announcement, *Graduate Study in Engineering and Applied Science,* which includes a description of graduate research and study opportunities in materials science and engineering, is available upon request (see p. 4). Further information may be obtained from the Graduate Faculty Representative (Materials Science and Engineering), Bard Hall.

Mechanical and Aerospace Engineering

Upson and Grumman Halls

E. L. Resler, Jr., director; A. R. George, assistant director; P. L. Auer, D. L. Bartel, C. A. Berg, J. F. Booker, W. W. Carson, D. A. Caughey, B. Conta, P. C. T. de-Boer, F. C. Gouldin, S. Leibovich, W. J. McLean, L. Phoenix, P. T. Radulovic, A. R. Seebass, S. F. Shen, D. G. Shepherd, K. E. Torrance, K. K. Wang, R. L. Wehe, J. R. Zimmerman. Members of the faculty of the graduate Fields of Aerospace Engineering and of Mechanical Engineering are listed under the two fields.

Courses of instruction are listed on pp. 112–120.

Aerospace Engineering

Degrees Offered: Master of Engineering (Aerospace), Master of Science, Doctor of Philosophy.

Faculty members of the graduate Field of Aerospace Engineering: P. L. Auer, D. A. Caughey, P. C. T. de-Boer, R. H. Gallagher, A. R. George, G. S. S. Ludford, E. L. Resler, Jr., A. R. Seebass, S. F. Shen, D. L. Turcotte.

Aerospace engineering deals with a large variety of physical problems which have their origins in the flight of aircraft and space vehicles in atmospheric and space environments. This field has always been at the frontier of new technology, and the innovative use of the basic physical sciences has always been a necessity. The tradition of the former Graduate School of Aerospace Engineering, now part of the Sibley School of Mechanical and Aerospace Engineering, is being maintained. The primary objective of these programs is the education and preparation of selected engineering and science graduates to enter a profession of constant challenge and high intellectual satisfaction. The training emphasizes solid fundamentals in course work and active involvement in research areas of current importance. Diversification of student interest is encouraged; close contact with the faculty provides exceptional individual attention.

Superior facilities are available for experimental studies of all types of fluid and gas dynamics, and for work in plasma physics, chemical kinetics, and laser chemistry. Theoretical investigations of both fundamental and engineering significance in these and related areas are constantly in progress. Areas of recent interest are aerodynamic noise, sonic boom, nonlinear waves, combustion processes in low-pollution engines, and solution of flow problems by finite element and numerical methods. In addition to close collaboration with the graduate Field of Mechanical Engineering, there is close cooperation with the Laboratory of Plasma Studies, the Center for Radiophysics and Space Research, the Center for Applied Mathematics, and the Department of Chemistry.

Preparation for Graduate Study

Applicants will be considered for this field if they hold baccalaureate degrees (or the equivalent) in any branch of engineering, mathematics, or the physical sciences from qualified institutions, provided that their undergraduate scholastic records indicate ability to pursue graduate study successfully.

The Cornell programs of study in engineering physics, electrical engineering, and mechanical engineering are especially recommended to undergraduates who expect to study aerospace engineering at the graduate level. The introductory courses Aerospace Engineering IMT305 and IMT606 would be useful electives. All students who expect to enter the graduate Field of Aerospace Engineering should try to arrange their undergraduate programs to include courses in thermodynamics, fluid mechanics, applied mathematics, chemistry, and physics.

The Degree Programs

Master of Engineering (Aerospace)

Undergraduate students who have demonstrated more than average ability, have shown adequate promise for carrying on graduate study, and are interested in extending their education in the aerospace field by advanced training in analytical and research-oriented subjects are eligible for admission to this program. Candidates for a Ph.D. in this field who do not already hold a master's degree are encouraged to matriculate as candidates for the M.Eng. (Aerospace) degree.

The Master of Engineering program is designed to increase the student's facility in the application of the basic sciences to engineering problems of importance in this field. Because aerospace engineering is continually engaged in new areas, an essential guideline for this program is to reach beyond present-day practices and techniques. This is achieved by supplying the student with the fundamental background and the analytical techniques that will prove useful in all modern engineering developments.

Successful completion of the work for this degree requires that the student pass a series of courses in approved subjects. These include four three-hour core courses in various areas of aerospace engineering. The courses listed below represent typical ones acceptable for the degree requirements and permit candidates to study in any of four areas of aerospace engineering: (1) fluid mechanics, (2) high-temperature gasdynamics, (3) magnetohydrodynamics, and (4) theoretical aerodynamics. Active research in these areas is being carried out in the School. However, the faculty may modify this basic list to suit the needs, interests, and background of individual candidates. Other course sequences, leading to specialization in allied areas such as energy conversion, aerophysics, and chemical kinetics can be arranged.

Also required are six hours of elective subjects. In addition to those listed below, available elective subjects frequently include courses, in their specialties, offered by faculty and visiting staff members.

The other requirements for the M.Eng. (Aerospace) degree are six hours of mathematics (IAA680–681 or Mathematics 415–416 or the equivalent), attendance at the weekly colloquium (one credit hour per term), one advanced seminar (two hours), and one advanced project (two hours). This makes a total of thirty credit hours. In unusual circumstances, exceptions may be made at the discretion of the faculty. A candidate normally will have a background equivalent to an accredited four-year bachelor's degree program in aerospace or mechanical engineering or engineering physics. A student with a different background may be required to take additional courses to make up deficiencies.

It is not recommended that candidates enter the program at midyear, except in very unusual circumstances. Further inquiries may be addressed to the Program Representative, M.Eng. (Aerospace), Grumman Hall.

Available courses are listed below:

Available Core Courses for M.Eng. (Aerospace) Degree:	*Credits*
IMA611, Physics of Fluids I	3
IMP643, Combustion Processes	3
IMA621, Introductory Plasma Physics	3
IMA723, Special Topics in Plasma Physics	3
IMF632, Fluid Mechanics I	3
IMF633, Fluid Mechanics II	3
IMA602, Theoretical Aerodynamics I	3
IMA603, Theoretical Aerodynamics II	3

*Electives: List A**	
IMA612, Physics of Fluids II	3
IAG672–673, Space Flight Mechanics; Mechanics of the Solar System	6
IMA622, Introductory Magnetohydrodynamics	3
IMA704, Theory of Viscous Flows	3
IMA706, Atmospheric Motions	3
IMA707, Aerodynamic Noise Theory	3
IMA795, Special Topics in Aerospace Engineering	3
IMF734, Turbulence and Turbulent Flow	3

*Many of these courses are offered only if there is sufficient demand. Completion of the basic sequence or the equivalent is usually a prerequisite.

Electives: List B	*Credits*
IAA770, Foundations of Applied Mathematical Analysis	3
IAB663, Applied Elasticity	3
IAB664, Theory of Elasticity	3
IAB765, Mathematical Theory of Elasticity	3
IAC662, Vibration of Elastic Systems	3
IAC670, Intermediate Dynamics	3
IAC771, Advanced Dynamics	3
IAC675, Nonlinear Vibrations	3
IMF737, Numerical Methods in Fluid Flow and Heat Transfer	3
IMH650, Transport Processes	3
IMH651, Convection Heat Transfer	3
IMP643, Combustion Processes	3
IMP644, Seminar on Combustion	3
IMP655, Energy Conversion	3
IMT606, Aerospace Propulsion Systems	3
Physics 443, Atomics and Introductory Quantum Mechanics	4
Physics 444, Nuclear and High-Energy Particle Physics	4
Physics 454, Introductory Solid State Physics	4
Physics 510, Advanced Experimental Physics	3
Physics 561, Classical Electrodynamics	3
Physics 562, Thermal, Statistical, and Continuum Physics	3
Physics 572, Quantum Mechanics I	3
Physics 574, Quantum Mechanics II	3
Chemistry 780, Principles of Chemical Kinetics	4
Chemistry 796, Statistical Mechanics	4
IEE681, Introduction to Plasma Physics	3
IEE682, Advanced Plasma Physics	3
IEE731, Quantum Electronics I	3
IEE732, Quantum Electronics II	3

Master of Science and Doctor of Philosophy

Original work in aerospace engineering requires advanced courses and a thesis. This may lead to the degree of Master of Science or Doctor of Philosophy. Each student works closely with a faculty supervisor in the formulation of his or her individual program of course work and active research. The programs are flexible in order to accommodate the broad and changing nature of the field and the widest interests of the students, and to reflect the current needs of society and industry. This frequently results in close cooperation between the graduate Field of Aerospace Engineering and other fields and divisions of the University.

Faculty research in progress spreads over many areas. Fluid phenomena of diverse types have always been of prime importance. There are presently studies of the sonic boom, aerodynamic noise, ferrofluids, geophysical flows, unsteady boundary layers, and computational fluid mechanics. Research in applied physics and chemistry is represented by topics in chemical kinetics, gas lasers, and plasmadynamics. A novel design for a low-pollution automotive engine is being intensively tested, and a new project in combustion chemistry has begun. Other projects on energy and transportation problems, some jointly with the graduate Field of Mechanical Engineering, are under way.

The activities of the aerospace engineering faculty are best summarized through its research and published papers. Those interested in obtaining copies or abstracts of work recently completed should write to the Graduate Faculty Representative (Aerospace Engineering), Upson Hall. An announcement titled *Graduate Study in Engineering and Applied Science,* which includes a description of Aerospace Engineering, is also available (see p. 4).

Mechanical Engineering

Degrees Offered: Bachelor of Science, Master of Engineering (Mechanical), Master of Science, Doctor of Philosophy.

Mechanical engineering, the broadest of the several established fields of engineering, comprises two major streams of technology: (1) the transformation and utilization of energy, including fluid dynamics and heat transfer; and (2) the design and production of goods, machines, equipment, and systems. Accordingly, mechanical engineering at Cornell falls into two main areas of concentration: mechanical systems and design, and engineering of energy and fluid systems.

Because of the wide range of mechanical engineering, the four-year undergraduate program is designed to provide breadth of training, to develop in each student some depth of understanding of the engineering sciences basic to the field, and to provide an introduction to the professional and technical areas with which mechanical engineering is particularly concerned. The program has been designed to provide a great deal of flexibility to suit individual students' objectives.

This broad preparation leads to several possibilities for advanced study following the B.S. degree program. Possible graduate level programs at Cornell include:

1. *Graduate study leading to the degree of Master of Engineering (Mechanical).* This is a curricular type of professional program intended for those students who wish to practice mechanical engineering. Although the course of study is available for all qualified students who hold a baccalaureate degree in engineering, the program is specially adapted as a graduate year of study integrated with the previous work in the Sibley School of Mechanical and Aerospace Engineering. It is the program commonly taken by qualified students not planning to pursue research or teaching as a career or not changing their field for advanced work. Details of this program are given on the following pages.
2. *Graduate study leading to the degrees of Master of Science or Doctor of Philosophy, with majors in either mechanical design or energy and fluid systems.* Students planning to engage in research or teaching as a career would normally enroll in such a program. Information is given in the *Announcement of the Graduate School.*

3. *Graduate study in related fields,* such as aerospace engineering, industrial engineering, or nuclear science and engineering, or in different fields such as business administration, law, or medicine.

Areas of Concentration

Mechanical Systems and Design. This area is concerned with those aspects of mechanical engineering that involve the design, analysis, and manufacture of devices, machines, and systems. To follow a course of study in this area, students may elect courses that will equip them for a wide variety of engineering tasks; particular areas of concentration are vehicle engineering, and manufacturing and design.

Vehicle engineering is concerned with the transportation needs of modern society. It includes the consideration of wheeled and other transporters. Dynamic and safety aspects as well as structural features are considered. The course offerings are supplemented with independent projects.

Manufacturing and design is concerned with the economical design and production of material goods needed by society. Emphasis is placed on the interrelation of design and manufacture. Attention is paid to the newer production techniques (e.g., electromechanical machining, electrodischarge machining, explosive forming, numerical control, and automated production), and the traditional methods. Independent work in specialized areas is also offered.

Engineering of Energy and Fluid Systems. This area of concentration is concerned with the transformation, transfer, and utilization of energy, and with fluid dynamics. These concerns may be summarized as:

1. *Power and propulsion:* Conversion of energy for man's various requirements for electric power and transportation (terrestrial and aerospace). Students

are offered relevant elective courses treating power and aerospace propulsion systems, energy conversion, combustion and transport processes, and fluid mechanics.

2. *Environmental control:* The study of environmental modification, with emphasis on sources of pollutants, their distribution through the earth's waters and atmosphere, and technical alternatives that minimize or eliminate the impact of technologically originated pollution. The creation of artificial environments is considered. Relevant electives treat pollution problems, refrigeration and air conditioning, acoustics and noise, combustion engines, and the more fundamental topics already mentioned.

Theoretical and experimental research interests include high-temperature and nonequilibrium fluid dynamics, plasma processes, rotating fluids with application to the confinement of high-temperature gases and to natural processes in the atmosphere and oceans, problems of heat rejection to the environment — thermal pollution, combustion processes, air pollution, and fire research; convection, conduction, and radiative heat transfer.

The Degree Programs

Bachelor of Science

The four-year baccalaureate program in mechanical engineering begins in the Division of Basic Studies (DBS), which offers a freshman and sophomore curriculum that is substantially common to all undergraduate engineering students. Students who plan to enter the Field Program in Mechanical Engineering as upperclass students must elect, as one of their four sophomore engineering core sciences, the course IAK221, Mechanics of Solids. If they have a definite interest in mechanical engineering, it is strongly recommended, though not required, that they also take IMG221, Introduction to Thermodynamics, and IAK231, Dynamics, as two of their other sophomore engineering core sciences. This will allow a more flexible field program with an increased number of elective courses.

The upperclass curriculum comprises twenty courses. Eight are required by the College for all junior and senior students, and consist of four liberal studies electives, two technical electives, and two free electives. The Field Program in Mechanical Engineering comprises the other twelve courses: nine required, one elective in the area of mathematics (chosen from a list of approved courses), and two field electives (upperclass courses offered by the Sibley School of Mechanical and Aerospace Engineering). Of the nine required courses, three may be core sciences taken previously in DBS; in this case, released electives — chosen from offerings in the natural sciences, mathematics, or engineering — become available. Thus, the Field Program provides a great deal of flexibility: a minimum of four and a maximum of eight electives in technical areas are available during the junior and senior years. This flexibility requires careful planning by the students in consultation with their faculty advisers to ensure that they follow a meaningful program directed by their particular interests.

Field Program requirements are summarized as follows.

Required courses which may be taken as core sciences in DBS or as Mechanical Engineering Field courses:
IAK231, Dynamics
ITE261, Mechanical Properties of
  Materials (DBS)
or
IMM311, Materials and Manufacturing
  Processes (field course)
IEE210, Introduction to Electrical Systems
IMG221, Introduction to Thermodynamics

Other required courses:
IMF323, Fluid Dynamics
IMH324, Heat Transfer and Transport
  Properties
IMG325, Mechanical Design and Analysis
IMS326, Systems Dynamics
IMG453, Mechanical Engineering Laboratory

Elective courses:
A course in mathematics or mathematical methods, chosen from an approved list and taken during the junior or senior year. Two field electives selected from upperclass courses in mechanical engineering offered by the Sibley School of Mechanical and Aerospace Engineering.

One possible course sequence suitable for students who enter the Field Program with only one mechanical engineering required course (the entry requirement of IAK221, Mechanics of Solids) is given below as a guide to the development of a course program. Of course, many other programs are possible; for example, those students who have followed the recommendation to satisfy some field requirements by taking certain sophomore engineering core sciences are able to substitute released electives for them. Also, many courses may be taken in terms different from those indicated below. Each student arranges an individual schedule in consultation with a faculty adviser.

Term 5
IAK231, Dynamics
IMG221, Thermodynamics
IMM311, Materials and Manufacturing Processes
Mathematics elective
Liberal studies elective

Term 6
IMG325, Mechanical Design and Analysis
IMF323, Fluid Mechanics
IEE210, Introduction to Electrical Systems
Field elective
Liberal studies elective

Term 7
IMH324, Heat Transfer and Transport Processes
IMS326, Systems Dynamics
IMG453, Mechanical Engineering Laboratory
Technical elective
Liberal studies elective

Term 8
Field elective

Technical elective
Free elective
Free elective
Liberal studies elective

Field, technical, released, and free electives may be chosen to emphasize particular areas of mechanical engineering if desired. Several groupings of electives are given below to give some examples of such areas.

Design and analysis courses:
IMG325, Mechanical Design and Analysis
IMS326, Systems Dynamics
IMS389, Computer-Aided Design
IMD663, Mechanical Components
IMD464, Design for Manufacture
IMS677, Mechanical Vibrations
IMS674, Conceptual Design
IMS678, Automatic Control Systems
IMS690, Special investigations in Mechanical Systems

Materials processing, automation, and production systems electives:
IMD464, Design for Manufacture
IMS678, Automatic Control Systems
IMM311, Materials and Manufacturing Processes
IMM612, Analysis of Manufacturing Processes
IMM614, Introduction to Numerical Control
IMM690, Special Investigations in Materials Processing
ITE339 (Materials Science and Engineering), Materials Engineering
IIF303 (Civil and Environmental Engineering), Engineering Economics and Systems Analysis
IOR350 (Industrial Engineering and Operations Research), Cost Accounting, Analysis, and Control

Biomechanics electives:
IMB665, Biomechanical Systems — Analysis and Design
IMB690, Special Investigations in Biomechanical Systems
Agricultural Engineering 415, Physical Analysis of Plant and Animal Materials
Agricultural Engineering 685, Biological Engineering Analysis
IAH601 (Theoretical and Applied Mechanics), Biomechanics, Bioengineering, Bionics, and Robots

Vehicle engineering electives:
IMD663, Mechanical Components
IMS677, Mechanical Vibrations
IMT486, Automotive Engineering
IMS678, Automatic Control Systems
IMT687, Dynamics of Vehicles
IMP442, Pollution Control in Power and Propulsion
IMF636, Turbomachinery
IMP449, Combustion Engines
IID620 (Civil and Environmental Engineering), Transportation Engineering

Power and energy engineering electives:
IMG208, The Role of Energy in Society
IMP440, Thermodynamic Applications
IMP643, Combustion Processes
IMP655, Energy Conversion
IMG656, Energy and Fluid Systems Laboratory
IP303 (Applied and Engineering Physics), Introduction to Nuclear Science and Engineering
IMF632–633, Fluid Mechanics I and II
IMH650, Transport Processes
IMP658, Processes of Large Scale Heat Rejection
IMP656, Power Systems
IMP442, Pollution Control in Power and Propulsion
IMT606, Aerospace Propulsion Systems
IMF636, Turbomachinery
IMP449, Combustion Engines

Environmental control electives:
IMG654, Environmental Control
IMF339, Acoustics and Noise
IMP442, Pollution Control in Power and Propulsion
IMP643, Combustion Processes
IMP658, Processes of Large Scale Heat Rejection
Chemistry 389–390, Physical Chemistry I and II

Aerospace engineering electives:
IMT305, Introduction to Aeronautics
IMF632–633, Fluid Mechanics I and II
IMF636, Turbomachinery
IMT606, Aerospace Propulsion Systems
IAG672 (Theoretical and Applied Mechanics), Space Flight Mechanics
IAG673 (Theoretical and Applied Mechanics), Mechanics of the Solar System

Although there is no requirement for industrial experience, undergraduate students are urged to obtain summer employment that will broaden their knowledge of engineering. This is regarded as particularly desirable for those who plan to enter the professional program for the Master of Engineering degree. The University and College placement services can be helpful in finding employment opportunities. Industrial experience is also available to mechanical engineering students through the Engineering Cooperative Program (see p. 9), which provides for three work periods druing the upperclass years yet does not delay the normal graduation date.

Graduate Degrees

Faculty members of the graduate Field of Mechanical Engineering: D. L. Bartel, C. A. Berg, J. F. Booker, B. Conta, T. A. Cool, P. C. T. deBoer, F. C. Gouldin, S. Leibovich, W. J. McLean, F. K. Moore, R. M. Phelan, P. T. Radulovic, D. G. Shepherd, K. E. Torrance, K. K. Wang, R. L. Wehe.

Master of Engineering (Mechanical)

A one-year program building upon the undergraduate degree program in mechanical engineering leads to the professional degree of Master of Engineering (Mechanical). The emphasis is on the development of competence in professional subjects. Experience is provided through a team design project.

This program is designed to be flexible so that candidates may concentrate on any of a variety of specialty areas within the field of mechanical engineering. These areas include bioengineering, machine dynamics and control, mechanical analysis and development, vehicles and propulsion, propulsion engines, energy systems, thermal environment, manufacturing engineering, and material removal. Depending on the individual's preparation, at least half the course work is elective to some degree.

Admissions requirements are listed on p. 13. A minimum of two terms of full-time study with completion of at least thirty hours of course work is required to complete the degree program. It should be noted, however, that since the program is designed to follow the Cornell undergraduate program in mechanical engineering or the equivalent, students with other undergraduate backgrounds may have deficiencies that will necessitate additional work and perhaps more than the usual length of time to earn the degree. The M.Eng. program is generally taken as preparation for a practice-oriented career. However, if elective courses are chosen carefully, the program can be satisfactory preparation for a Ph.D. degree program or work of a research-and-development-oriented nature.

The usual curriculum is as follows:

Fall term	*Credits*
Mathematics	3
IMS770, Advanced Mechanical Analysis	3
IMG790, Mechanical Engineering Design Project	3
Engineering laboratory	3
Technical elective	3
Spring term	
Mathematics	3
Advanced energy and fluid systems course	3
IMG790, Mechanical Engineering Design Project	3
Mechanical engineering elective	3
Technical elective	3

It is recommended that the mathematics requirement be satisfied by Applied Mathematics IAA350–351 or, on a more advanced level, by IAA680–681. Courses offered by the Department of Mathematics may be taken with the approval of the adviser. If the six-hour mathematics requirement has been satisfied in advance by courses taken during the undergraduate years, these credit hours may be taken in technical elective subjects.

The schedule may be arranged to accommodate the energy and fluid systems course either term. The course is to be selected from the following: IMA611, Physics of Fluids I (fall); IMF632, Fluid Mechanics I (fall); IMH650, Transport Processes (fall); IMA612, Physics of Fluids II (spring); IMF633, Fluid Mechanics II (spring); IMP643, Combustion Processes (spring); IMP655, Energy Conversion (spring); and IMF737, Numerical Methods in Fluid Flow and Heat Transfer (spring). If two or more of these courses have been satisfactorily completed prior to entry in the program, any graduate-level course in the IMF, IMH, or IMP groups may be taken to satisfy the energy and fluid systems requirement.

The engineering laboratory course may be either IMD672, Experimental Methods in Machine Design (fall), or IMG656, Advanced Energy and Fluid Systems Laboratory (fall). Other laboratory courses given in the College of Engineering may be approved for qualified students if such courses are suitable for a particular objective.

The Mechanical Engineering Design Project, IMG790, requires individuals to work as members of a design team which is responsible for the preparation of a formal report at the end of the year. Some recent projects have been concerned with fly ash disposal, ocean current measurement, gas turbine load-test equipment, design of a tape splicer, planetary roving vehicles, geothermal power plants, and assistive devices for hands and legs. Some projects are suggested, monitored, and reviewed by outside organizations, whose engineers work with the student project groups and participate in a technical session when the project reports are presented at the end of the year.

Some scholarship aid is available. Admission and scholarship application forms may be obtained by writing to the Office of the Chairman, Graduate Professional Engineering Programs, 323 Upson Hall. Further information on the program can be obtained from the Office of the Director, Sibley School of Mechanical and Aerospace Engineering, 105 Upson Hall.

Master of Science and Doctor of Philosophy

The general and special requirements for these degrees in the graduate Field of Mechanical Engineering are given in the *Announcement of the Graduate School* (see p. 4).

There is no required pattern of courses; an individual program of formal or informal study is arranged by a student in consultation with a Special Committee that is selected by the student. The required thesis study is usually related to general or special interests of a faculty member of this field.

Fellowships, research assistantships, and teaching assistantships are available. Further information may be obtained by writing to the Graduate Faculty Representative (Mechanical Engineering), Sibley School of Mechanical and Aerospace Engineering, Upson Hall.

Nuclear Science and Engineering

Ward Laboratory of Nuclear Engineering

Degrees offered: Master of Engineering (Nuclear), Master of Science, Doctor of Philosophy.

Faculty of the engineering Field of Nuclear Engineering supervising the M.Eng. (Nuclear) degree: K. B. Cady, A. P. Casarett, D. D. Clark, C. D. Gates, H. H. Fleischmann, B. S. Isacks, V. O. Kostroun, C.-Y. Li, S. Linke, F. K. Moore, M. S. Nelkin, J. S. Thorp, R. L. Von Berg.

Faculty of the graduate Field of Nuclear Science and Engineering supervising the Master of Science and Doctor of Philosophy degrees: the persons listed above and, in addition, R. M. Littauer and G. H. Morrison.

Courses of instruction are listed under Applied and Engineering Physics on pp. 71–74.

Nuclear science and nuclear engineering are concerned with the understanding, development, and practical application of scientific knowledge of nuclear reactions and radiations.

The programs at Cornell are designed to accommodate students who are interested in nuclear physics, nuclear engineering, radiation protection, or some combination of these. Subjects in nuclear physics include low-energy nuclear structure, atomic structure, and phenomena involving interactions between nuclear and atomic processes. Nuclear engineering involves the basic sciences of chemistry, physics, and mathematics in combination with the skills of metallurgical, chemical, civil, electrical, and mechanical engineering—with the goal of designing safe, efficient nuclear energy systems. Radiation protection, nuclear safety, and environmental effects of nuclear energy utilization constitute a third important area of study; in addition to inclusion of these topics in the regular nuclear engineering courses, an undergraduate course IP201, Nuclear Energy and the Environment, is offered, and graduate students have the opportunity to take courses in radiation biology taught in the Department of Physical Biology.

The aims of the Cornell programs are to provide the student with a thorough understanding of the scientific principles upon which nuclear systems are based, to develop the skills of applying these principles to engineering problems, and (in the M.S. and Ph.D. programs) to develop research abilities.

To implement these aims, Cornell offers three graduate degrees: a professional degree, Master of Engineering (Nuclear), administered by the Engineering Field of Nuclear Engineering, and two research degrees, Master of Science and Doctor of Philosophy, administered by the graduate Field of Nuclear Science and Engineering.

Appropriate undergraduate programs which can lead to graduate study in nuclear science and engineering are physics, engineering physics, or civil, chemical, electrical, mechanical, or materials engineering, or a suitable set of courses in the College Program. Students should select their technical electives carefully to ensure that they meet the entrance requirements for the graduate program they intend to enter.

Laboratory and Research Facilities

The Ward Laboratory of Nuclear Engineering contains: (1) A TRIGA research reactor with a steady-state power of 100 kilowatts and a pulsing capability of 250 megawatts providing sources of neutrons and gamma rays for activation analysis, solid and liquid state studies, and nuclear physics research. In addition to standard pneumatic and mechanical transfer systems for activated specimens, the reactor is equipped with a 50 millisecond rapid transfer mechanism in one of the six beam ports; (2) a critical facility or "zero power reactor" of versatile design for basic studies of reactor physics, such as space dependent reactor kinetics and noise analysis; (3) a 3 MV positive-ion accelerator for studies of radiation effects and low energy nuclear reactions; (4) a shielded gamma cell with 5,000 curies of Co^{60} for radiation chemistry studies; (5) a radiochemistry laboratory; and (6) subcritical assemblies for reactor physics investigations.

The Degree Programs

Undergraduate Study

Students are encouraged to begin specialization in nuclear science and engineering at the undergraduate level. This can be done by choice of electives within regular Field Programs such as engineering physics, or within the College Program by selection of appropriate courses with the approval of the College Program Committee.

Major in Nuclear Engineering. A student majoring in nuclear engineering under the College Program would take IP201, Nuclear Energy and the Environment, and IP303, Introduction to Nuclear Science. Also required would be two of the following courses: IP612, Nuclear Reactor Theory I; IP651, Nuclear Measurements Laboratory; IP633, Nuclear Reactor Engineering; and IP609, Low-Energy Nuclear Physics.

College Program in Energy Conversion. This Program is a synthesis of nuclear, thermal, and electrical engineering and is described in the College Program section of this Announcement (see p. 39).

Master of Engineering (Nuclear)

This two-term curriculum is intended primarily for individuals who want a terminal professional degree, but it may also serve as preparation for doctoral study in nuclear science and engineering. The course of study covers the basic principles of nuclear reactor systems with a major emphasis on reactor safety and radiation protection and control. There is a growing need in the nuclear industry and the regulatory agencies for engineers who have a thorough knowledge of these safety provisions and who are able to apply it to the design of reactor plants and auxiliary equipment and to the implementation of environmental monitoring systems. Required courses in the Master of Engineering (Nuclear) program treat reactor safety and radiation protection and control in depth, and an elective course in radiation biology and an elective seminar in physical biology are available.

The background recommended for the M.Eng. (Nuclear) degree program includes: (1) a baccalaureate degree in engineering, physics, or applied science; (2) modern physics; (3) mathematics, including advanced calculus; and (4) thermodynamics.

Students should see that they fulfill these requirements before beginning the program. In some cases, deficiencies in preparatory work may be made up by informal study during the preceding summer.

The interdisciplinary nature of nuclear engineering allows students to enter from a variety of undergraduate specializations. Our students in the past have had widely varying background preparations including physics, engineering physics, mechanical engineering, chemical engineering, electrical engineering, civil engineering, materials science and engineering, and nuclear engineering.

The thirty credit hours for the degree include the following courses:

Fall term
IP612, Nuclear Reactor Theory I
IP633, Nuclear Reactor Engineering
IP609, Low-Energy Nuclear Physics
Technical elective

Spring term
IP651, Nuclear Measurements Laboratory
Technical elective
Engineering Design Project
Mathematics or physics elective

The engineering electives should be in a subject area relevant to nuclear engineering, such as energy conversion, radiation protection and control, feed-back control systems, magnetohydrodynamics, controlled thermonuclear fusion, and environmental engineering. Typical examples of courses that might be chosen by Master of Engineering (Nuclear) degree candidates are: Physical Biology 922, Biological Effects of Radiation; IMP655, Energy Conversion; IMH651, Convection Heat Transfer; IEE681, Introduction to Plasma Physics; IEE682, Advanced Plasma Physics; IMA621, Introductory Plasma Physics; IMA622, Introductory Magnetohydrodynamics; and IEE671 – 672, Feedback Control Systems.

Admission and scholarship application forms may be obtained by writing to the Office of the Chairman, Graduate Professional Engineering Programs, 323 Upson Hall. Further information on the nuclear science and engineering professional program may be obtained by writing to the Ward Laboratory of Nuclear Engineering.

Master of Science and Doctor of Philosophy

The M.S. and Ph.D. programs are oriented toward research, and require completion of a thesis as well as course work. A candidate for one of these degrees chooses either *nuclear science* or *nuclear engineering* as his or her major subject, but because each student plans an individual program in consultation with the faculty members of the Special Committee, there are no detailed course requirements. This approach, long a tradition of graduate study at Cornell, is well suited to interdisciplinary fields such as nuclear science and engineering. Independent thesis research along with formal and informal discussions with staff members and other students is a vital part of the program.

If a student choses *nuclear science* as his or her major subject, thesis research may be undertaken in any of the following areas: nuclear structure physics, atomic physics and x-ray phenomena, nuclear astrophysics, nuclear chemistry, nuclear instrumentation, radiation chemistry, and radiation effects on materials. If a student selects *nuclear engineering*, the following areas are possible: experimental and analytical reactor physics, reactor plant dynamics and safety, radiation protection and control, neutron transport theory and kinetic theory, nuclear energy conversion, nuclear environmental engineering, and nuclear structural engineering.

The appropriate preparation for graduate work in these programs is an undergraduate education in science, applied science, or engineering, with special emphasis on mathematics and modern physics.

Additional information on the M.S. and Ph.D. programs is available in the *Announcement of the Graduate School,* and the Announcement, *Graduate Study in Engineering and Applied Science* (see p. 4). Further information may be obtained from the office of the Graduate Faculty Representative (Nuclear Science and Engineering), Ward Laboratory of Nuclear Engineering.

Operations Research

Upson Hall

Degrees Offered: Master of Science, Doctor of Philosophy. The School of Industrial Engineering and Operations Research administers the undergraduate program in Industrial Engineering and Operations Research and the Master of Engineering (Industrial) degree program (see pp. 48–52).

R. E. Bechhofer, chairman, L. J. Billera, E. K. Clemons, R. W. Conway, J. E. Dennis, Jr., D. R. Fulkerson, D. C. Heath, J. C. Kiefer, W. F. Lucas, W. R. Lynn, W. L. Maxwell, J. A. Muckstadt, G. L. Nemhauser, N. U. Prabhu, T. J. Santner, B. W. Saunders, A. Schultz, Jr., F. L. Spitzer, M. S. Taqqu, H. M. Taylor, 3d., M. J. Todd, L. E. Trotter, Jr., B. W. Turnbull, L. I. Weiss.

Courses of instruction are listed on pp. 104–109.

The Field of Operations Research offers doctoral programs in the major areas of operations research, applied probability and statistics, systems analysis and design, and industrial engineering. Master of Science programs are offered in all the above areas, and in information processing. It is expected that doctoral programs with majors in the areas of information processing and mathematical programming will be available in the near future. In addition, the areas of systems analysis and design and of industrial engineering will be combined into the major area of industrial and systems engineering.

A general description of the current major areas is given below.

Operations Research

The problem areas and techniques of operations research are approached from a highly analytical viewpoint. Theories and techniques from mathematical programming (linear, nonlinear, dynamic, and probabilistic), combinatorics, theory of games, stochastic processes, and scheduling and simulation are developed and used extensively. Consideration is given to constructing appropriate mathematical models to represent various real-life operational systems, and to developing techniques for analyzing the performance of these models.

The operations research student pursues a course of study and research that emphasizes the use of the mathematical, probabilistic, statistical, and computational sciences in the development of the techniques of operations research. The student's ultimate goal may range from making a fundamental contribution to the techniques of operations research to applying these techniques to problems in diverse professional fields.

Applied Probability and Statistics

This subject of study and research is designed for students having primary interests in the techniques and associated underlying theory of probability and statistics, particularly as they are applied to problems arising in science and engineering. The techniques emphasized are those associated with applied stochastic processes (for example, queuing theory, traffic theory, inventory theory, and time-series analysis) and statistics (including statistical decision theory; the statistical aspects of the design, analysis, and interpretation of experiments, and of ranking and selection theory; sampling inspection; and acceptance sampling).

Students who elect work in this area are expected to acquire considerable knowledge of the theory of probability and statistics. All students who major in applied probability and statistics are required to minor in mathematics.

Systems Analysis and Design

Although the solution of systems problems requires knowledge of underlying theory, the inherent practical limitations of the problem must be understood. Analysis of a system alone is insufficient; alternative solutions must be generated before selection of the one which can best be integrated with other elements of the system. Modeling concepts are equally important, but only when they can produce workable systems. Illustrations of the design of integrated systems can be found in industry, the environment, commerce, and government. A good example is the design of urban traffic control systems. Research activity may involve the development of new methodology or the synthesizing of new combinations from what is already known. The goal is to improve the understanding of systems or to develop new decision criteria for systems.

Industrial Engineering

Studies of the analysis and design of the complex operational systems that occur in industry, particularly in manufacturing, are included in this subject. Plant design, cost analysis and control, and production planning are some of the major topics. A student is expected to have considerable facility in the modern analytical techniques associated with rational decision making and the establishment of valid design criteria. These techniques are drawn from among inventory theory, queuing theory, mathematical programming, quality control, reliability theory, and computer simulation.

Because the design and operation of modern engineering systems apply to areas other than manufacturing, the use of the word "industrial" should not be considered restrictive. Industrial engineers frequently are employed as systems specialists in commerce, banking, distribution, merchandising, and hospital management.

Information Processing

Information processing deals with the analysis and design of systems that record, transmit, store, and process information. Emphasis is on the application and integration of equipment rather than on the design of machines. Areas of interest include systems for information retrieval, manufacturing control, and traffic control. This subject also includes such underlying theoretical topics as data structure, operating system organization, and computing language structure.

The principal computing facility at Cornell is an IBM 370/168, located in Langmuir Laboratory at the Cornell Research Park on the periphery of the campus and directly linked to satellite computers at five different campus locations. The College of Engineering is served through one of these satellite stations in Upson Hall, as well as by a number of teletypewriter terminals in different locations. There are more than a score of other computer installations on the campus, ranging up to a PDP-11. These are special-purpose installations and access is usually restricted.

The Degree Programs

Master of Science and Doctor of Philosophy

These degree programs, administered by the Graduate School of the University, are described in the *Announcement of the Graduate School.*

Major and minor subjects are chosen from those areas outlined above. Minors can also be subjects offered by other units of the University; appropriate minors that have been chosen most frequently in recent years, and the departments or schools which offer courses of study in them are: applied mathematics (Applied Mathematics), computer science (Computer Science), econometrics and economic statistics (Economics), public systems planning and analysis (Civil and Environmental Engineering), managerial economics (Business and Public Administration), mathematics (Mathematics), and planning theory and systems analysis (City and Regional Planning).

A prerequisite for graduate study in the Field of Operations Research is a bachelor's degree in engineering, mathematics, economics, or the physical sciences, awarded by an institution of recognized standing. The candidate must have a commendable undergraduate scholastic record and must supply other evidence of an interest in and ability to pursue advanced study and research in his or her proposed major and minor subjects. Submission of the results of the Graduate Record Examination is strongly recommended for all applicants and is required for fellowship and assistantship applicants.

Further information may be obtained by writing to the Graduate Faculty Representative (Operations Research), Upson Hall.

Structural Engineering

See p. 36.

Theoretical and Applied Mechanics

Thurston Hall

Degrees Offered: Master of Engineering (Engineering Mechanics), Master of Science, Doctor of Philosophy.

Y.-H. Pao, chairman; H. D. Block, J. A. Burns, H. D. Conway, E. T. Cranch, J. C. Dunn, J. T. Jenkins, R. H. Lance, S. A. Levin, G. S. S. Ludford, F. C. Moon, S. Mukherjee, R. H. Rand, W. H. Sachse.

Courses of instruction are listed on pp. 120–123.

The Department of Theoretical and Applied Mechanics is responsible for undergraduate and graduate instruction and research in theoretical and applied mechanics and applied mathematics. The subject matter in these areas is of a fundamental nature, and the undergraduate courses provide a substantial part of the basic engineering science education for engineering students. In addition to the required core courses, the undergraduate can elect advanced courses which are especially suited to students who have demonstrated superior analytical or experimental ability and who wish to extend and develop this ability. The Department offers undergraduate programs in individualized major and minor subjects through the College Program described below and on p. 38.

The Degree Programs

The Undergraduate College Program

The Department sponsors an undergraduate College Program in engineering science that has a science-based curriculum flexible enough to be adapted to special or developing interests. It is designed for engineering students who want to emphasize basic engineering sciences; who want flexibility in their undergraduate curricula; whose interests are not reflected by any of the major engineering disciplines; or who want to postpone specialization.

There are general guidelines for the curriculum giving broad course areas of engineering science which must be taken, but no specific prescribed courses beyond those required of all engineering students during their first two years in the Division of Basic Studies. The idea is to develop a solid understanding of the basic science behind all engineering, and to supplement this with study in a particular area, such as astronomy, applied mathematics, physics, chemistry, or biology. A typical program is shown on p. 41.

Any faculty member of the Department of Theoretical and Applied Mechanics can sponsor an individual student who wishes to plan a College Program in engineering science. The choice of particular courses is based on the educational goals of the student, and is made jointly by the student and his or her adviser.

It should be noted that this is a College-approved curriculum equivalent to a Field Program. It provides the opportunity for choice of professional specialization within a sound, science-based curriculum, and it offers maximum flexibility in curriculum. Further information may be obtained from faculty members of the Department.

Master of Engineering (Engineering Mechanics)

Students interested in advanced study in mechanics who intend to emphasize engineering practice rather than teaching or research may apply for admission to the M.Eng. (Engineering Mechanics) degree program. This course of study is designed to allow the student to master advanced topics in mechanics and, at the same time, to develop facility in applying fundamental concepts in mechanics to modern engineering problems. No formal thesis is required for this degree; however, the student is required to carry out an individual project, either analytical or experimental in nature, under the supervision of a faculty member.

Admission requirements are: (1) a baccalaureate degree in engineering or applied science; and (2) a cumulative grade-point average of at least 2.5 in the undergraduate curriculum. Undergraduate programs of non-Cornellians must, in the judgment of faculty members in the field, provide adequate preparation in mechanics.

Degree requirements are: (1) completion of a minimum of three credit hours of work on an individual project under the direction of a faculty member; (2) satisfactory completion of six credit hours of course work in mathematics or applied mathematics (which may be satisfied by the Theoretical and Applied Mechanics course sequence IAA680–681 or the equivalent); and (3) courses in or relating to theoretical and applied mechanics, selected in consultation with the student's adviser from those offered at the graduate level, to bring the total credit hours to at least thirty.

A general description of the Master of Engineering degree is given on p. 13. Further information may be obtained from members of the Department.

Master of Science and Doctor of Philosophy

These research-oriented degrees, administered by the Graduate School of the University, require submission of a thesis. A description is given in the *Announcement of the Graduate School* (see p. 4). A special Announcement, *Graduate Study in Engineering and Applied Science,* includes a more detailed description of the Field of Theoretical and Applied Mechanics.

The graduate program in mechanics and applied mathematics emphasizes fundamental understanding of the newest developments in engineering and applied science. The basic nature of the studies encourages research that cuts across and extends various traditional engineering fields and ensures that the specialist will find many opportunities to work, either in industry or in academic institutions, on advanced engineering projects for which conventional training is often inadequate.

Graduate students may pursue programs involving theoretical or experimental work in the following areas of specialization.

1. Space mechanics, including research on orbits of satellites; the dynamics of solar system bodies; applications of functional analysis to optimal control theory.

2. Acoustic and elastic waves; waves in layered media; scattering of elastic waves and dynamic stress concentrations; waves in composite materials.

3. Structural mechanics, including the mechanics of composite materials, and of static and dynamic loadings; linear and nonlinear vibrations and buckling.

4. Theory of elasticity, inelasticity, and plasticity, including the effects of high-temperature environment.

5. Experimental mechanics, including linear and nonlinear vibrations, wave propagation and damping measurements in solids, mechanical behavior of composite materials, magnetoelasticity, ultrasonics, and nondestructive testing of materials.

6. Continuum mechanics: nonlinear elasticity and thermoelasticity; nonlinear viscoelasticity of solids and fluids; continuum theories of structured solids and fluids.

7. Biomechanics and bionics; artificial intelligence and robots; pattern classification; biodynamics.

8. Theoretical fluid mechanics and related applied mathematics, with research in dynamics, magnetohydrodynamics, and combustion.

The flexibility of the graduate study programs at Cornell permits students to draw on several divisions of the University for supporting work in pure and applied science. Graduate students interested primarily in theoretical and applied mechanics and applied mathematics find these supporting fields of interest: mathematics, structures, applied physics, mechanical and aerospace engineering, soil mechanics, and physics.

Additional information may be obtained by writing to the Graduate Faculty Representative (Theoretical and Applied Mechanics), Thurston Hall.

Program on Science, Technology, and Society

R. Bowers, director.

The purpose of the interdisciplinary Program on Science, Technology, and Society is to stimulate and initiate teaching and research on the interaction of science and technology with contemporary society, and to provide coherence and support for current University activities in this area. Students and faculty from all parts of the University are welcome to participate in the Program's activities.

Topics of concern to the Program include: technology assessment; biomedical ethics; national science policy; sociology of science; and science, technology, and the humanities. These and other subjects are studied through courses, graduate and faculty seminars, workshops, and individual research programs. The Program also participates in the graduate minor field of public policy, offering a science policy "stream" within this minor field. The following courses are cosponsored by the Program on Science, Technology, and Society in collaboration with other units of the University.

Biological Sciences 206, Biomedical Ethics. Fall. S. M. Brown, Jr., L. Purdy.

Biological Sciences 207, Environmental Ethics. Spring. S. M. Brown, Jr., L. Purdy.

Business and Public Administration NPA504 and Government 626, Public Policies for Science and Technology in the United States. Fall. F. A. Long.

[Business and Public Administration NCE510 and Government 630, Science, Technology, and Development. Spring. M. J. Esman and others. Not offered 1975–76.]

[Business and Public Administration NCE513 and Government 683, Science, Technology, and International Relations. Spring. M. J. Esman. Not offered 1975–76.]

Computer Science 105, The Computerized Society. Fall. A. Borodin.

Engineering IIB203, Social Implications of Technology. Fall. W. R. Lynn, E. D. Heitowit.

Engineering IIF605, The Law and Environmental Control. Fall.

Engineering IIF606, Seminar in Technology Assessment. Spring.

Engineering IMG302, Technology and Society—An Historical Perspective. Spring. B. J. Conta.

Government 312, Urban Studies Laboratory. Fall and spring. D. E. Van Houweling.

Government 384, Defense Policies and Arms Control. Spring. F. A. Long and G. H. Quester.

History 280, Freshman Seminar in the History of Technology. Fall. J. H. Weiss.

[History 386 and Philosophy 386, Problems in the Philosophy and History of Biology. Spring. R. N. Boyd, W. B. Provine. Not offered 1975–76.]

[Law 578, Legal and Market Controls of Technological Change. Fall. J. P. Brown. Not offered 1975–76.]

Seminar on Science, Technology, and Law. Fall. K. L. Hanslowe.

Philosophy 681, Philosophy of Science. Fall. M. Black.

Sociology 403, Sociology of Science and Technology. Spring. G. A. Gordon.

Sociology 529, Demographic and Ecological Models of Science. Spring. D. E. Chubin.

Urban Planning and Development 434, Economics 302, and Government 302, The Impact and Control of Technological Change. Spring. J. E. Milch.

Urban Planning and Development 533 and Government 629, The Politics of Technical Decisions. Fall. J. E. Milch.

Program information and course descriptions may be obtained from the Program office, 614 Clark Hall.

Cornell University

Description of Courses

Courses designed for the underclass curriculum are described under Division of Basic Studies (see p. 21). Other engineering courses are listed under the school or department which offers them. Descriptions of courses in the humanities, social sciences, and physical and natural sciences are given in the *Announcement of the College of Arts and Sciences: Courses of Study* and other University Announcements. A general list of subjects offered throughout the University, with references to the various divisions that offer them, is included in the *Announcement of General Information*.

Each engineering course is designated by two or three letters and three figures. The letters signify, in order, the college; the school or department; and an optional classification of varying significance, assigned by the school or department. The code letter for the College of Engineering is I, and therefore the first letter of all engineering courses is I. The second and optional third letters are assigned according to the following code:

Applied and Engineering Physics	P
Basic Studies	BE
Chemical Engineering	HE
Civil and Environmental Engineering	I
Computer Science	CS
Electrical Engineering	EE
Geological Sciences	GE
Industrial Engineering and Operations Research	OR
Materials Science and Engineering	TE
Mechanical and Aerospace Engineering	M
Theoretical and Applied Mechanics	A

(Agricultural Engineering Courses are classified under the College of Agriculture and Life Sciences.)

The three figures in each course number are assigned according to levels which have the following significance:

100—introductory courses; open to all levels of qualified students; no prerequisites
200—lower division (freshman and sophomore) courses; open to all levels of qualified students; may have prerequisites
300—upper division (junior and senior) courses; may have prerequisites
400—upper division (senior and graduate level) courses; 200 or 300 level courses or the equivalent required as prerequisites
500—professional courses; open to all qualified students
600—graduate courses; also available to upper division students
700—graduate courses; open to graduate students only
800—thesis or research at the master's degree level
900—thesis or research at the doctoral level

Because many faculty advisers and students are more familiar with the previous course numbering system, a Reference List of Current and Former Numbers, arranged by area of instruction, is provided toward the back of this book, following the course descriptions.

All academic courses of the University are open to students of all races, religions, ethnic origins, ages, sexes, and political persuasions. No requirement, prerequisite, device, rule, or other means shall be used by any employee of the University to encourage, establish, or maintain segregation on the basis of race, religion, ethnic origin, age, sex, or political persuasion in any academic course of the University.

Division of Basic Studies

See p. 21.

Aerospace Engineering

See p. 112.

Agricultural Engineering

(For a complete description of the courses in agriculture, see the *Announcement of the College of Agriculture and Life Sciences.)*

151 Introduction to Agricultural Engineering Measurements and Graphics Fall. Credit one to three hours. Two lecture/laboratory sessions. Prerequisite: one term of calculus or concurrent registration. Staff.
The subject will be presented in modular form. Module I, T laboratory, consists of the introduction to engineering measurements, including graphics and the basics of PL/C. Module II, F laboratory, examines basics of surveying measurements. Module I and Module II will be completed during the first nine weeks of the semester, and each will confer one credit hour. Module III, T laboratory, will enable the student to apply measurement principles and computer skill to a typical engineering problem. Module IV, F laboratory, will enable the student to apply surveying knowledge and skill to an applied engineering problem. Module III and Module IV will start the tenth week and continue to the end of instruction; each will confer one-half credit.

152 Engineering Measurements and Graphics Spring. Credit one to three hours. Two lecture/laboratory sessions. Prerequisite:151 or consent of instructor. Staff
The subject will be presented in modular form. Module I, T laboratory, will consist of engineering measurements, graphics, and PL/C. Module II, F laboratory, will consist of graphics, including work on machine drawings, intersections, developments, descriptive geometry, and use of conventional practices and symbols. These modules will be completed during the first nine weeks, and each will confer one credit. Module III, T laboratory, will enable the student to apply the measurement principles and computer skill to a typical engineering problem. Module IV, F laboratory, will enable the student to apply graphic skills to selected problems. Module III and Module IV will start the tenth week and continue to the end of instruction; each will confer one-half credit.

221 Plane Surveying. Fall. Credit three hours. Two lectures, one laboratory. Staff.
An introduction to plane surveying. Use and care of equipment is stressed, using field problems related to construction and mapping.

222 Engineering Surveys Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: 221 or equivalent. Staff.
An introduction to photogrammetric measurements, hydrologic surveys, route surveys, mapping, and control surveys of limited extent. The use of measurements in the solution of engineering problems will be emphasized.

401 Special Topics in Agricultural Engineering Fall. Credit one hour. Open only to seniors. W. W. Gunkel.
Presentation and discussion of the opportunities, qualifications, and responsibilities for positions of service in the various fields of agricultural engineering.

415 Physical Analysis of Plant and Animal Materials Spring. Credit two hours. Two lectures. Prerequisite: one semester of calculus. G. E. Rehkugler.
A study and analysis of the physical properties of plant and animal materials. The definition of pertinent physical properties and development of the meaning of a physical property. The morphology of plant and animal materials will be related to problems of defining physical properties. Specifically, material product geometry will be examined and the influence of forces on behavior of materials will be studied. Physical properties of plant and animal materials will be related to material and manipulative forces applied in growth, harvesting, processing, and handling. The deformation and flow of these materials will be modeled. Interpretation of physical properties of plant and animal materials will be used in defining texture of food materials and mechanical damage to plant products.

416 Laboratory Practice in Physical Analysis Spring. Credit one hour. May be taken without 415 by permission of the instructor. One laboratory/recitation session. Prerequisite: one semester of calculus. Laboratories and recitation will be offered in alternate weeks. G. E. Rehkugler.
Laboratory component of course 415. Laboratory practice will be in the physical analysis of plant and animal materials.

450 Introduction to Analog Computation Fall. Credit two hours. One lecture, one laboratory. R. B. Furry.
Fundamentals of analog computing with elementary examples of applications from biological and physical systems. Includes basic computing elements, analog programming, scaling, and computer operation. An attempt will be made to permit students to work on a problem related to their own areas of interest. A basic knowledge of differential equations is required.

[**461 Agricultural Machinery Design** Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: mechanical design and analysis. W. W. Gunkel. Not offered 1975–76.
The principles of design and development of agricultural machines to meet functional requirements. Emphasis is on computer-aided analysis and design, stress analysis, selection of construction materials, and testing procedures involved in agricultural machine development. Engineering creativity and design related to agricultural production systems are also stressed.]

462 Agricultural Power Fall. Credit three hours. Two lectures, one laboratory. Prerequisite: engineering mechanics (dynamics), or equivalent. W. W. Gunkel.
Utilization of internal combustion engine and other forms of energy in agriculture. Basic theory, analysis, and testing of internal combustion engines for use in farm tractors and other agricultural power applications. Specific study of tractor transmissions. Nebraska Tractor Tests, and soil mechanics related to traction and vehicle mobility. Economics and human factors in power use and application will be considered.

[465 **Processing and Handling Systems for Agricultural Materials** Spring. Credit three hours. Three lectures, one laboratory. R. B. Furry. Not offered 1975–76.
Processes such as size reduction, separation, metering, and drying. Psychrometrics, fluid flow measurement, and an introduction to dimensional analysis and controls for agricultural applications. Problem solutions will employ both analog and digital computers; it is preferred that the student know how to write programs to utilize the digital computer.]

471 Soil and Water Engineering Fall. Credit three hours. Two lectures, one discussion-laboratory. Prerequisites: fluid mechanics or hydraulics and soils, or concurrent registration; farm management recommended. L. G. James.
The application of engineering principles to problems of soil and water management. Design and construction of drainage, irrigation and erosion control systems, small reservoirs, and earth embankments.

475 Systems Models for Environmental Quality Control Fall. Credit three hours. Prerequisite: one year of college mathematics. Three lectures. D. A. Haith.
Introduction to systems analysis techniques and their application to environmental quality management. The course will emphasize the use of mathematical modeling to evaluate alternative solutions to environmental problems. The techniques of simulation, linear programming, and dynamic programming will be introduced and applied to such areas as water quality control, solid waste management, air pollution control, and agricultural waste management.

481 Agricultural Structures Design Spring. Credit two hours. One lecture, one recitation-laboratory. Prerequisite: structural engineering. N. R. Scott.
Application of basic structural concepts to design of agricultural structures. Emphasis on wood structures, including design of trusses, rigid frames, prefabricated panels, and columns. Design of reinforced concrete members and steel members. Economic considerations are presented also.

482 Environmental Control for Animals and Plants Spring. Credit two hours. One lecture, one recitation-laboratory. Prerequisite: thermodynamics. N. R. Scott.
Study of thermal interchanges between animals, including man, and plants with the environment. Understanding of physiological principles affecting thermal comfort and health. Ventilation, air conditioning, psychrometrics, insulation, condensation control, solar energy, and weather phenomena.

491 Highway Engineering (Same as Civil and Environmental Enginering IID632.) Fall. Credit three hours. Two lectures, one laboratory. Prerequisite: IID301 recommended. L. H. Irwin.
Study of economic considerations in road improvement, planning and programming, road location and geometric design, traffic engineering, engineering soil characteristics and classification, design of roadbed thickness, drainage, stabilization methods and materials, wearing surfaces. Emphasis is on secondary roads.

492 Bituminous Materials and Pavement Design Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: 491 recommended. L. H. Irwin.
Properties of asphalts, aggregates, and bituminous mixtures, bituminous mixture design; pavement construction; soil stabilization methods; seal coat and surface treatment design and construction; pavement maintenance; flexible pavement design methods; rigid pavement design methods; pavement design for frost conditions.

[495 **Transportation Policies for Developing Nations, with Emphasis on Low-Volume Roads** Fall. Credit three hours. Two lectures. Prerequisites: upperclass or graduate standing and permission of committee. Limited to forty-five students. Core committee consists of: L. H. Irwin, coordinator, agricultural engineering; G. J. Cummings, rural sociology; and D. F. Williams, policy planning and regional analysis. Not offered 1975–76.
A multidisciplinary study of the processes of policy formulation and planning of transportation facilities in developing nations with different energy resources. Areas of investigation will include: the policymaking process and strategy for policy implementation, economic policy and economic analysis methods for transportaion, sociological considerations of transportation policy, and technology of road building. A term project and report on an appropriate aspect of transportation for developing nations will be required.]

551–552 Agricultural Engineering Project Credit six hours. Required for M.Eng. degree. G. E. Rehkugler and staff.
Comprehensive design projects utilizing real engineering problems to present fundamentals of agricultural engineering design. Emphasis on formulation of alternate design proposals, including economics and nontechnical factors and complete design of the best alternative.

651 Similitude Methodology Spring. Credit three hours. Two lectures, one laboratory. R. B. Furry.
Similitude methodology, including the use of dimensional analysis to develop general equations to define physical phenomena, model theory, distorted models, and analogies, with an introduction to a variety of applications in engineering. It is preferred that the student know how to write programs to utilize the digital computer before enrolling in the course.

652 Instrumentation Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: consent of instructor. N. R. Scott.
Emphasis is on the application of instrumentation concepts and systems to physical and biological measurements. Characteristics of instruments, application of operational amplifiers and transistors for signal conditioning and interfacing, shielding and grounding; transducers for measurement of force, pressure, displacement, velocity, acceleration, temperature, light, and flow; and data acquisition systems, including telemetry, are considered.

[**675 Solid Waste Management** (Same as Civil and Environmental Engineering IIE630.) Spring. Credit three hours. Prerequisite: consent of instructor. Not offered 1975–76.
Study of municipal, industrial, and agricultural solid wastes. Emphasis on waste characteristics, method of treatment and disposal, and interrelationship with air, water, and land environment. Discussion of economic and political aspects. Intended primarily for graduate students but open to qualified undergraduates.]

676 Industrial Waste Management (Same as Civil and Environmental Engineering IIE631.) Spring. Credit three hours. Primarily a graduate course, but open to upperclass students in chemical, agricultural, or civil and environmental engineering, or in the College Program with a major from these fields.
Legal aspects, assimilatory capacity of receiving waters, joint industrial-municipal collection of wastes, and sewerage service charges. Waste sampling and analysis, treatment processes, waste-reduction possibilities, water quality and quantity, water reuse and recovery, and costs. Specific industrial operations and selected case studies of Industrial waste treatment. An in-depth study of a particular waste problem is required of all students.

677 Treatment and Disposal of Agricultural Wastes Fall. Credit three hours. Prerequisite: consent of instructor. W. J. Jewell.
Emphasis is on the causes of agricultural waste problems and on the fundamentals and application of possible treatment and disposal practices to control the problems. The course is aimed at having the students understand how to make decisions about selecting and utilizing appropriate agricultural waste management processes and systems, as well as how to design and operate the systems. Aerobic and anaerobic processes, nutrient control, waste utilization, and land disposal are discussed. The students will apply these and other concepts to the management of wastes from specific animal and crop production and food processing operations. Integration of feasible waste management methods into agricultural production constitutes a major part of the course.

678 Environmental Quality Management for Agro-Ecosystems (Same as Civil and Environmental Engineering IIF751.) Fall. Credit three hours. Prerequisite: some knowledge of linear programming or consent of instructors. C. Shoemaker, D. A. Haith.
The application of systems analysis and mathematical ecology to problems in ecosystem management and environment quality. Topics to be considered will be selected from the following: pest control, fertilizer usage, eutrophication, agricultural waste, soil and water conservation, and public policy decisions affecting ecosystem management.

679 Use of Land for Waste Treatment and Disposal Spring. Credit three hours. Prerequisite: permission of instructor. W. J. Jewell, P. J. Zwerman.
The socio-legal-technical factors that dictate that disposal of wastes on land be a major alternative in all waste management schemes. The properties of land and crop systems that make land disposal of wastes a viable alternative. Evaluation of present land treatment and disposal regulations for the development of new regulations and the design of full scale units.

685 Biological Engineering Analysis Fall. Credit four hours. Three lectures. Prerequisite: IAA351 or consent of instructor. J. R. Cooke.
Engineering problem-solving strategies and techniques will be explored. The student will solve several representative engineering problems which inherently involve biological properties. The mathematical modeling will emphasize problem formulation and interpretation of results. The student's knowledge of fundamental principles will be extensively utilized. Principles of feedback control theory will be applied to biological systems.

700 Agricultural Engineering Seminar Fall and spring. Staff.
Presentation and discussion of research and special developments in agricultural engineering and other fields.

750 Orientation for Research Fall. Credit one hour. R. B. Furry.
Introduction of newly joining graduate students to departmental research policy, programs, methodology, resources, and candidate responsibilities and opportunities.

761 Power and Machinery Seminar Spring. Credit one hour. Prerequisite: consent of instructor. Staff.
Study and discussion of research and new developments in agricultural power and machinery.

771 Soils and Water Engineering Seminar Spring. Credit one to three hours. Prerequisite: consent of instructor. Staff.
Study and discussion of research on selected topics in irrigation, drainage, erosion control, and agricultural hydrology.

775 Agricultural Waste Management Seminar Fall and spring. Credit one hour. Prerequisite: consent of instructor. Staff.
Study and discussion of the management of agricultural waste, with emphasis on the physical, chemical, biological, economic, and aesthetic requirements.

781 Agricultural Structures and Related Systems Seminar Spring. Credit one hour. Prerequisite: consent of instructor. Staff.
Study and discussion of farmstead production problems, with emphasis on biological, economic, environmental, and structural requirements.

785 Biological Engineering Seminar Spring. Credit one hour. Prerequisite: consent of instructor. N. R. Scott, J. R. Cooke.
The interaction of engineering and biology will be examined, especially the environmental aspects of plant, animal, and human physiology, in order to improve communications between engineers and biologists.

Applied and Engineering Physics

IP751 and IP752 Project Fall and spring. Credit three hours.
Informal study under direction of a member of the University staff. The objective is to develop self-reliance with initiative, as well as to gain experience with methods of attack and overall planning in examining a special problem related to the student's field of interest.

IP490 Informal Study in Engineering Physics Laboratory or theoretical work in any branch of engineering physics under the direction of a member of the staff.

IP217 Contemporary Topics in Applied Physics Spring. Credit three hours. Prerequisite: Physics 213.
Lecture periods combined with recitations and some experiments. Two lectures, one recitation-laboratory each week. V. O. Kostroun and staff.
See description on p. 25 under Division of Basic Studies.

IP323 Statistical Thermodynamics Fall. Credit four hours. T. N. Rhodin.
Quantum statistical basis for equilibrium thermodynamics, canonical and grand canonical ensembles, and partition functions. Quantum and classical ideal gases and para-magnetic systems, Fermi-Dirac, Bose-Einstein, and Maxwell-Boltzmann statistics. Introduction to systems of interacting particles. At the level of *Thermal Physics* by Kittel and *Statistical and Thermal Physics* by Reif.

IP424 Statistical Physics Spring. Credit four hours. R. V. Lovelace.
Elementary kinetic theory of gases in terms of the single-particle distribution function: transport processes involved in viscosity, heat conductivity, particle diffusion, and electrical resistivity; the Boltzmann equation and the H theorem. Fluctuations and irreversible processes: the master equation, the Langevin equation, the Fokker-Planck equation, and Brownian movement; electromagnetic noise and Nyquist's theorem; the Wiener-Khintchine relations; entropy production and the Onsager reciprocal relations.

IP333 Mechanics of Particles and Solid Bodies Fall. Credit four hours. Three lectures, one recitation.
Primarily for majors in engineering physics. Newton's laws; coordinate transformations; generalized coordinates and momenta, Lagrangian and Hamiltonian formulation; applications to oscillator, restrained motion, central forces, small vibrations of multiparticle systems, motion of rigid body.

IP434 Continuum Physics Spring. Credit four hours. Three lectures, one recitation.
Stress tensor, equation of reaction, Euler's equation, incompressible and compressible flow, strain tensor, elements of elasticity theory, elastic waves, viscous liquids and anelastic solids.

IP355 Intermediate Electromagnetism Fall. Credit four hours. Prerequisites: Physics 214 and 216 and coregistration in Mathematics 421, or consent of instructor. B. R. Kusse.
Topics include vector calculus, electrostatic and magnetostatic fields as solutions of boundary value problems, dielectric and magnetic media, mechanical and electric energy and pressure. Also electric induction phenomena, skin effect, and the introduction of displacement current. Emphasis on the application of concepts to physical phenomena and engineering. At the level of *Lectures on Physics,* Vol. II, by Feynman, and *Foundations of Electromagnetic Theory* by Reitz and Milford.

IP456 Intermediate Electrodynamics Spring. Credit four hours. Prerequisite: IP355, coregistration in Mathematics 422, or consent of instructor. T. A. Cool.
Development of electromagnetic wave phenomena and radiation. Topics include transmission lines, waveguides, wave properties of dispersive media, radiation and scattering phenomena, reciprocity, physical optics, and special relativity. Emphasis is on concepts and their application to physical phenomena and engineering. At the level of *Lectures on Physics,* Vol. II, by Feynman, and *Classical Electromagnetic Radiation* by Marion.

IP461 Introductory Quantum Mechanics Spring. Credit four hours. Three lectures, one recitation. Prerequisites: IP333 or Physics 318; coregistration in Mathematics 422 and in IP456 or Physics 326.
A first course in the systematic theory of quantum phenomena. Topics will include wave packets and the Schroedinger equation, illustrative solutions for the square well, harmonic oscillator, and the hydrogen atom, the formal structure of quantum mechanics, angular momentum, spin, and the exclusion principle, perturbation theory, and an introduction to symmetries and to the quantization of the electromagnetic field. This course, which is similar in content to Physics 443, is offered in the spring semester to allow flexibility in scheduling. At the level of Chapters 4 through 9 of *Modern Physics* and *Quantum Mechanics* by Anderson.

IP711 Principles of Diffraction (Same as Materials Science and Engineering ITE706.) Fall. Credit three hours.
Broad introduction to diffraction phenomena as applied to solid state problems. Production of neutrons and x-rays, scattering and adsorption of neutrons, electrons, x-ray beams. Diffraction from two- and three-dimensional periodic lattices. Crystal symmetry, Fourier representation of scattering centers, the effect of thermal vibrations on scattering. Phonon information from diffuse x-ray and neutron scattering and Bragg reflections. Standard crystallographic techniques for single crystals and powders. Diffraction from almost-periodic structures, surface layers, gases, and amorphous materials. Survey of dynamical diffraction from perfect and imperfect lattices. Techniques for imaging structural defects. At the level of *Optical Principles of the Diffraction of X-Rays* by R. W. James, *X-Ray Diffraction* by B. E. Warren, *Electron Diffraction* by Vainshtein, and *Electron Microscopy of*

Thin Crystals by Hirsch, et al. Lectures accompanied by experiments on fluorescence and polarization of x-rays, diffractometer measurements of vibrational amplitudes in crystals, natural widths of emission lines, identification of crystal structures, crystal orientation by back reflection techniques.

IP712 Selected Topics in Diffraction (Same as Materials Science and Engineering ITE712.) Spring. Credit three hours.
Ewald-von Laue dynamical theory applied to x-ray and high energy electron diffraction in solids. Thermal scattering and measurement of phonon dispersion, frequency spectrum, interatomic force constants, Debye temperatures, vibrational amplitudes. Diffuse scattering, short and long range order, precipitation in solids, point defects.

IP753 Seminar Topics in Applied Physics Either term. Credit one hour. Primarily for candidates for the Master of Engineering (Engineering Physics) degree. The student is expected to attend and participate in a minimum of fifteen scheduled University seminars and/or colloquia chosen in technical or scientific areas close to that of the student's chief interest. A brief summarizing report on each of these seminars is presented to the staff member overseeing the course. It is expected that the seminar material may be augmented by reference to and inclusion of related research reported in the literature and read by the student.

IP761 Kinetic Theory (Same as Electrical Engineering IEE781.) Fall, alternate years. Credit three hours. Two lectures. Prerequisite: Physics 561, 562, or consent of instructor. R. L. Liboff.
Designed for students who want a firm foundation in fluid dynamics, plasma-kinetic theory, and nonequilibrium statistical mechanics. Brief review of classical dynamics. The concept of the ensemble and the theory of the Liouville equation. Prigogine and Bogoliubov analyses of the BBKGY sequence. Master equation, density matrix, Wigner distribution. Derivation of fluid dynamics, Boltzmann, Krook, Fokker-Planck, Landau, and Balescu-Lenard equations. Properties and theory of the linear Boltzmann collision operator. Chapman-Enskog and Grad methods of solution of the Boltzmann equation. Klimontovich formulation. Kubo theory. Coarse graining and ergodic theory. At the level of *Introduction to the Theory of Kinetic Equations* by Liboff.

IP762 Physics of Solid Surfaces (Same as Materials Science and Engineering ITE762.) Spring. Credit three hours. A lecture course for graduate students and upperclassmen. T. N. Rhodin, J. M. Blakely.
Equilibrium thermodynamics and statistical mechanics of interfaces. Atomic structure of surfaces in equilibrium. Surface fields, dipoles, and defects in insulators. Electronic and vibrational properties of surfaces. Surface barriers and work functions, surface vibrational and electronic states. Kinetic processes at surfaces. Mass and charge transport. Condensation and evaporation processes. Experimental techniques. Materials drawn from research papers and various review articles in journals such as *Progress in Materials Science, Advances in Chemistry,* and *Solid State Physics.*

IP201 Nuclear Energy and the Environment Fall. Credit three hours. Two lectures and one two-hour recitation or laboratory each week. The level of presentation assumes knowledge of introductory physics, chemistry, and calculus, but previous knowledge of biology is not required. V. O. Kostroun.
Fundamentals of nuclear radiations and their measurement and interaction with matter, the natural radiation environment, and sources of man-made radioactivity (five weeks); radiation chemistry, radiation biology, somatic and genetic effects of nuclear radiation, movement of radioactive materials in the biosphere, and bases of radiation protection standards (five weeks); environmental effects of nuclear electricity generation and nuclear fuel mining, processing and waste storage, control of radiation hazards, and waste heat problems (four weeks).

IP303 Introduction to Nuclear Science and Engineering Spring. Credit three hours. Prerequisites: sophomore physics and mathematics.
An introductory course in low-energy nuclear physics and nuclear engineering for juniors and seniors not majoring in engineering physics. The objective is to acquaint students with low-energy nuclear physics and some of its practical applications. The following topics will be covered: elementary quantum mechanics; properties and structure of nuclei; radiations emitted by nuclei and their interaction with matter; nuclear reactions, with emphasis on fission and fusion processes; the neutron chain reaction; types and uses of nuclear radiations, such as neutron activation analysis and radioactive tracer analysis.

IP609 Low-Energy Nuclear Physics Fall. Credit four hours. Three lectures. Prerequisite: an introductory course in modern physics including quantum mechanics.
The nuclear interaction. Properties of ground and excited states of nuclei; models of nuclear structure; alpha, beta, gamma radioactivity; low-energy nuclear reactions — resonant and nonresonant scattering, absorption, and fission. At the level of *Introduction to Nuclear Physics* by Enge.

IP612 Nuclear Reactor Theory I Fall. Credit four hours. Three lectures. Prerequisites: one year of advanced calculus and some familiarity with nuclear physics.
A first course in the physical theory of fission reactors. The fission process and the essential properties of neutron interactions with matter are described. The theory of neutron diffusion, slowing down, and thermalization is developed. The theory is applied to calculations of criticality and neutron flux distribution in nuclear reactors. Attention is restricted to idealized configurations in order to illustrate the physical ideas involved. Nuclear reactor kinetics and neutron transport theory are introduced. At the level of *Nuclear Reactor Theory* by Lamarsh.

IP613 Nuclear Reactor Theory II Spring. Credit three hours. A continuation of IP612, primarily intended for students planning research in nuclear

reactor physics and engineering. Three lectures. Prerequisite: IP612. K.B. Cady.
The Boltzmann linear transport equation, its adjoint, and their approximate solutions are developed and applied to the heterogeneous neutron chain reactor. The theories of fast fission effect, resonance escape, and thermal utilization are developed for heterogeneous reactors. The escape probability formulation of reactor lattices, the neutron importance function, perturbation theory, temperature coefficients of reactivity, and fission product poisoning are also treated. At the level of *The Physical Theory of Neutron Chain Reactors* by Weinberg and Wigner.

IP633 Nuclear Reactor Engineering Fall. Credit four hours. Prerequisite: introductory course in nuclear engineering. K. B. Cady.
A selected set of topics representing the fundamentals of nuclear reactor engineering: energy conversion and power plant thermodynamics, reactor plant fluid flow and heat transfer, thermal stresses, radiation protection and shielding, routine and accidental discharge of radionuclides from nuclear reactors, and nuclear fuel cycles. At the level of *Nuclear Reactor Engineering* by Glasstone and Sesonske.

IP634 Nuclear Engineering Design Seminar Spring. Credit four hours. Prerequisite: IP633. K. B. Cady.
A group design study of a selected nuclear reactor system. Emphasis is on safety, siting, and radiation protection in the design of nuclear power systems.

IP636 Seminar on Thermonuclear Fusion Reactors Spring. Credit three hours. Prerequisite: a basic course in plasma physics or nuclear reactor engineering, or consent of instructor. H. H. Fleischmann.
The present state of the technological and engineering problems expected in the design and construction of thermonuclear fusion reactors will be analyzed. Topics will include basic reactor containment schemes, materials development, mechanical and heat transfer problems, refueling, radiation and safety hazards, superconducting magnets, energy conversion, and economics.

IP651 Nuclear Measurements Laboratory Spring. Credit four hours. Two 2½-hour afternoon periods. Prerequisite: some knowledge of nuclear physics.
Laboratory experiments plus lectures on interaction of radiation with matter and on radiation detection, including electronic circuits. Twenty different experiments are available in the fields of nuclear and reactor physics and radiation protection. Among these are experiments on emission and absorption of radiation, radiation detectors and nuclear electronic circuits, interactions of neutrons with matter (absorption, scattering, moderation, and diffusion), activation analysis and radiochemistry, and properties of a sub-critical assembly. Many of the experiments use the TRIGA Reactor. The student is expected to perform eight to ten experiments selected to meet the student's needs. Some stress is placed on independent work by the student. At the level of *Nuclear Radiation Detection* by Price.

IP652 Advanced Nuclear and Reactor Laboratory Spring. Credit three hours. Two 2½-hour afternoon periods. Prerequisites: IP651 and IP609 or IP612. Offered on independent study basis or, if sufficient demand, as a formal course.
Laboratory experiments and experimental methods in nuclear physics and reactor physics. Ten different experiments are available, some using the Zero Power Reactor critical facility.

IP401 Physics of Atomic and Molecular Processes Fall. Credit three hours. Prerequisite: IP461, Physics 443, or consent of instructor. T. Cool.
An introduction to the basics of contemporary problems in the physics of atomic and molecular processes, including atomic structure, chemical bonding, radiation resonance processes, and elastic and inelastic collisions.

[**IP705 Topics in Statistical Physics** Fall. Credit three hours. Prerequisite: general familiarity with statistical mechanics. M. S. Nelkin. Not offered 1975–76.
Selected topics of current interest in statistical physics. For example, in 1974 the subject was the nonlinear behavior of macroscopic systems driven far from thermal equilibrium; the primary illustrative examples were from fluid mechanics.]

IP606 Introduction to Plasma Physics (Same as Electrical Engineering IEE681.) Fall. Credit three hours. Three lectures. Prerequisite: IP355, IP456, or equivalent. Open to fourth-year students at discretion of instructor. R. N. Sudan.
Plasma state; motion of charged particles in fields; adiabatic invariants, collisions, coulomb scattering; Langevin equation; transport coefficients, ambipolar diffusion, plasma oscillations and waves; hydromagnetic equations; plasma confinement, energy principles, and microscopic instabilities; test particle in a plasma; elementary applications. At the level of *Elementary Plasma Physics* by Longmire.

IP607 Advanced Plasma Physics (Same as Electrical Engineering IEE682.) Spring. Credit three hours. Three lectures. Prerequisite: IP606. R. N. Sudan.
Boltzmann and Vlasov equations; moments of kinetic equation; Chew-Goldberger-Low theory; waves in hot plasmas; Landau damping. Solution of the Vlasov equation by characteristics; ion acoustic instability; streaming instabilities; Bernstein modes; instabilities due to anisotropies in velocity space; gradients in magnetic field, temperature, and density. Absolute and convective instabilities; effects of collisions and Fokker-Planck terms; method of dressed test particles; high-frequency conductivity and fluctuations; neoclassical toroidal diffusiom, relativistic beams.

IP608 Plasma Astrophysics (Same as Astronomy 660.) Spring. Credit two hours. R. V. E. Lovelace.
A selection of topics are discussed in depth: a) the generation of noise by turbulence and the heating of the solar corona; the Parker model of the solar wind; magnetic fields in the corona and in interplanetary space; fluctuations in the magnetic field and plasma density of the solar wind; b) the propagation of cos-

mic rays in randomly irregular magnetic fields (Jokipii's theory); the cosmic-ray streaming instabilities and related effects (theories of Kulsrud and Pearce, Wentzel, and Skilling); and c) the theory of aligned rotating magnetospheres (theory of Goldreich and Julian).

IP619 Molecular Energy Transfer Spring. Credit three hours. T. A. Cool.
Fundamentals of energy transfer by molecular collisions in gases. Energy transfer mechanisms in molecular and chemical lasers. Intermolecular potential, dispersion forces, multipole moment interactions, repulsive forces. Processes for interconversion of vibration, rotation, and translational energy. Perturbation methods in vibrational energy transfer. Survey of experimental data and techniques for measurement of rates of energy transfer: shock tubes, laser-induced fluorescence, laser schlieren, optic acoustic effect. Transfer chemical lasers, vibration-vibration pumping, dissociation lasers. Laser diagnostics of chemically reacting systems.

IP622 Electron Microscopy and Diffraction Spring. Credit three hours. J. Silcox.
A discussion of selected topics in the areas of electron microscopy and diffraction, with the major emphasis on microscopy. Probable topics include: elastic and inelastic electron scattering from atoms, molecules, and aggregates of matter; nature of image formation—amplitude, phase, and diffraction contrast; resolution; magnetic domain structure as a phase grating and atomic planes as a diffraction grating; kinematical 2-beam, and n-beam dynamical theories of perfect crystals; phenomenological treatment of absorption; extension to imperfect crystals—diffraction contrast from defects such as dislocations, stacking faults, coherent and incoherent precipitates; discussion of inelastic scattering; instrumental and fundamental limitations on source properties and image formation capabilities and reasons for current research activities devoted to extending the capabilities.

IP621, IP623 Electron Microscopy: Image Formation, Image Processing, and Applications to Biomolecular Materials Fall.
This course will be given as a proseminar divided into three coherent but separate topics, each four to five weeks in duration. All three sections may be taken as IP621 for three credit hours or as IP623 for one or two credit hours if the student wishes to take only one or two of the topics. Prerequisite: consent of instructor. B. M. Siegel.
The three topics are (in the order they will be discussed): (1) imaging in the electron microscope—the basic electron optical system, specimen-electron interaction, image formation and optical transfer of information, parameters determining contrast and resolution; (2) image processing—methods and applications of coherent optical image reconstruction and computer processing, noise filtering, two-dimensional image restoration, determination of complex scattered wave, object-support separation, three-dimensional reconstruction; (3) application of electron microscopy in biomolecular investigations—current levels of observation, examples, limitations set by beam damage and specimen preparation, possibilities and prospect of obtaining high resolution information (less than thirty Angstrom units).

[**IP601 Photosynthesis** (Same as Biological Sciences 545.) Fall. Credit two hours. Prerequisites: Chemistry 104 or 208, Mathematics 108, 111, or 191, and Physics 102, 208, or 214, or consent of instructor. Past or current registration in IP605 is recommended. R. K. Clayton. Not offered 1975–76.
A detailed study of the process by which plants use light in order to grow, emphasizing physical and physico-chemical aspects of the problem.]

IP603 General Photobiology (Same as Biological Sciences 547.) Fall. Credit two hours. Prerequisites: Chemistry 104 or 208, Mathematics 108, 111, or 191, and Physics 102, 208, or 214, or consent of instructor. R. K. Clayton.
A study of the major interactions between light and living matter as encountered in photosynthesis, vision, regulation of physiology and development, bioluminesence, and damage by ultraviolet and visible light.

IP605 Optics in Biology (Same as Biological Sciences 405.) Fall. Credit two hours. Prerequisites: Chemistry 104 or 208, Mathematics 108, 111, or 191, and Physics 102, 208, or 214, or consent of instructor. R. K. Clayton.
Lectures, problems, demonstrations, and laboratory experience in applications of optics to biology. Topics include geometrical optics as applied to illumination systems, methods for studying biological effects of light, and analytical uses of optical absorption and fluorescence.

IP306 The Physics of Life Spring. Credit three hours. Two lectures. Prerequisite: Physics 213 or consent of instructor. A. Lewis.
This course, which deals with the physics of life within the unity and interdependence of living matter, is among the engineering core sciences. See description under Division of Basic Studies.

IP610 Biophysical Processes Spring. Credit three hours. Prerequisite: basic courses in biology, physics, physical chemistry, or mathematics such as IP323, Physics 315 or 341, Chemistry 390, or Mathematics 422, or consent of instructor. W. W. Webb.
Introduction to physical aspects of biological processes; statistical thermodynamics of solutions of macromolecules and weak electrolytes; dissipative processes, diffusive, convective, electrochemical, and coupled transport; chemical kinetics; multiphase systems, colloids and membranes; multiphase macrostructures; some physical probes.

Chemical Engineering

IHE101 Nonresident Lectures Fall. One lecture. Staff.
Given by lecturers invited from industry and from

selected departments of the University for the purpose of assisting students in their transition from college to industrial life.

IHE110 Mass and Energy Balances Either term. Credit three hours. Prerequisite: one year of freshman chemistry or consent of instructor. R. G. Thorpe.
Self-paced audiovisual instruction in the material of IHE111. See description under Division of Basic Studies.

IHE111 Mass and Energy Balances Fall. Credit three hours. Three lectures, one computing session. Prerequisite: one year of freshman chemistry or consent of instructor. R. G. Thorpe.
Engineering problems involving material and energy balances. Batch and continuous reactive systems in the steady and unsteady states. Humidification processes. (See also IHE110.)

IHE311 Equilibria and Staged Operations Fall. Credit three hours. Three lectures, one computing session. J. L. Anderson.
Phase equilibria and phase diagrams. The equilibrium stage, mathematical description of single and multistage operations, analytical and graphical solutions.

IHE312 Chemical Engineering Thermodynamics Fall. Credit three hours. Three lectures. Prerequisites: IHE311, Chemistry 287, 288. K. B. Bischoff.
A study of the first and second laws with application to batch and flow processes. Physical and thermodynamics properties, availability, free energy, chemical equilibrium. Applications to gas compression, refrigeration, power generation, adiabatic reactors, and chemical process development.

IHE321 Materials Spring. Credit five hours. Three lectures, two laboratories. G. G. Cocks.
An introduction to the structure and properties of solid materials. The polarizing microscope is used for examining materials in the laboratory. Topics include: testing of materials, bonding of atoms, crystal structure, phase transformation, forming and fabrication, production of materials, selection of materials, and behavior under service conditions. Laboratory topics include: optics of the microscope, geometrical and optical crystallography, and the physical chemical behavior of materials.

IHE410 Reaction Kinetics and Reactor Design Spring. Credit three hours. Three lectures. Prerequisite: IHE430. J. F. Stevenson.
A study of chemical reaction kinetics and principles of reactor design for chemical processes.

IHE430 Introduction to Rate Processes Fall. Credit three hours. Three lectures, one computing session. Prerequisites: IHE111 and engineering mathematics sequence. F. Rodriguez.
Fundamentals of fluid mechanics and heat transfer; solutions to problems involving viscous flow, heat conduction and convection, dimensional analysis, friction factors and heat transfer coefficients, macroscopic balances, elementary applications.

IHE431 Analysis of Separation Processes Spring. Credit three hours. Three lectures, one computing session. Prerequisites: IHE430 and familiarity with FORTRAN or PL/I. R. G. Thorpe.
Analysis of separation processes involving phase equilibria and rate of mass transfer; extensive use of the digital computer. Phase equilibria; binary, multicomponent, and extractive distillation; liquid-liquid extraction; gas absorption.

IHE432 Unit Operations Laboratory Fall. Credit three hours. Two lectures, one laboratory. Prerequisite: IHE430. R. L. VonBerg and staff.
Laboratory experiments in fluid dynamics, heat and mass transfer. Correlation and interpretation of data. Technical report writing.

IHE433 Project Laboratory Fall and spring. Credit variable. Prerequisite: IHE432.
Special laboratory projects involving bench-scale or pilot-plant equipment.

IHE461 Chemical Process Evaluation Fall. Credit three hours. H. F. Wiegandt.
A study of the important chemical processes.

IHE462 Chemical Process Synthesis Spring. Credit four hours. J. C. Smith, R. L. VonBerg.
A consideration of process and economic alternatives in selected chemical processes, along with technological assessment.

IHE563 Process Equipment Design and Economics Fall. Credit three hours. Three lectures. Prerequisite: IHE430 and IHE431, or equivalent. J. C. Smith and staff.
Performance, selection, and design of process equipment; storing, transporting, mixing, heating, and separating fluids and solids. Methods for estimating capital and operating costs. Process development and design.

IHE564 Design of Chemical Reactors and Multiphase Contacting Systems Fall. Credit three hours. Three lectures. P. Harriott.
Design, scale-up, and optimization of chemical reactors with allowance for heat and mass transfer, nonideal flow, and catalyst aging. Selection of systems for gas-liquid-solid contacting, including stirred tanks and fluidized beds.

IHE565 Design Project Spring. Credit three or six hours. Prerequisites: IHE563, IHE564. R. L. VonBerg and staff.
Design study and economic evaluation of a chemical processing facility, alternative methods of manufacture, raw material preparation, food processing, waste disposal, or some other aspect of chemical processing.

IHE595, IHE596 Special Projects in Chemical Engineering Either term. Credit variable.
Research or studies on special problems in chemical engineering.

IHE611 Phase Equilibria Fall. Credit three hours. Three lectures. Prerequisite: physical chemistry.

R. G. Thorpe.
A detailed study of the pressure-temperature-composition relations in binary and multicomponent heterogeneous systems where several phases are of variable composition. Prediction of phase data.

IHE621 Petroleum Refining Fall. Credit three hours. Three lectures. Prerequisite: IHE430. H. F. Wiegandt.
A critical analysis of the processes employed in petroleum refining.

IHE625 Economics of the Chemical Enterprise Spring. Credit three hours. Three lectures. Prerequisite: IHE561.
Research economics, feasibility studies, information sources; venture analysis; planning.

IHE627 Nuclear and Reactor Engineering Spring. Credit two hours. Two lectures. Prerequisite: consent of instructor. R. L. Von Berg.
Fuel processing and isotope damage, biological effects and hazards, shielding, radiation chemistry.

IHE628 Inventions, Patents, and Trade Secrets Spring. Credit three hours. R. York.
Protection of inventions and trade secrets. Statutory and other level requirements for patentability of inventions. Evaluation of patents. Role and management of patents in planning growth and expansion into new product lines.

IHE629 Development Economics Spring. Credit three hours. R. York.
Planning, evaluation, and management of development activities in the process industries as related to research, processing, new products, markets, and long-range growth.

IHE630 New Separation Techniques Fall. Credit three hours. Three lectures.
Lectures, problems, and demonstrations of new or less common separation techniques such as chromatography; ion exchange, electrophoresis, and membrane operations; analysis, design, and scale-up.

[**IHE631 Mixing and Mechanical Separations** Fall. Credit three hours. Three lectures. Prerequisite: IHE430 or consent of instructor. Not offered 1975–76.
Principles of mixing of gases, liquids, and solids; agitation, solid suspension; gas dispersion and chemical reaction; filtration; sedimentation; special mechanical separations.]

IHE640 Polymeric Materials Fall. Credit three hours. Three lectures. F. Rodriguez.
Chemistry and physics of the formation and characterization of polymers. Principles of fabrication.

IHE641 Properties of Polymer Materials Spring. Credit one to three hours. Three lectures. Prerequisite: IHE640 and/or IHE430. J. F. Stevenson, F. Rodriguez.
Polymer rheology: measurement of material functions, generalized Newtonian models, linear and nonlinear viscoelasticity. Special topics in polymeric materials.

IHE642 Polymeric Materials Laboratory Spring. Credit two or three hours. One or two laboratories. Prerequisite: IHE640. F. Rodriguez.
Experiments in the formation, characterization, fabrication, and testing of polymers.

IHE643 Engineering Analysis of Physiological Systems Spring. Credit three hours. K. B. Bischoff, J. F. Stevenson.
Engineering analysis and mathematical description of flow, transport phenomena, and chemical reactions involved in physiological system function. Cell and body fluid properties, the circulatory system and blood flow, renal system models, transport of drugs and other solutes, artificial organ design.

IHE644 Fermentation Engineering Fall. Credit three hours. Two lectures, one recitation. Prerequisites or corequisites: Chemistry 288 and any course in microbiology.
An advanced discussion of fermentation as a unit process. Topics include sterilization, aeration, agitation, and continuous fermentation.

IHE645 Industrial Microorganisms Spring. Credit two hours. Prerequisites: organic chemistry and physical chemistry.
A brief introductory course in microbiology for students with a good background in chemistry.

IHE647 Wastewater Engineering in the Process Industries Fall. Credit three hours. Prerequisites: organic and physical chemistry; IHE430 or equivalent. M. L. Shuler.
Introduction to general and legal problems of pollution control, including some descriptive technology. Major emphasis, however, is on the quantitative engineering aspects of design and operation. Both biological and physical chemical methods, as they apply to the treatment of strong and special wastes from the chemical and allied industries, are discussed.

IHE648 Polymer Processes Spring. Credit three hours. Three lectures. Prerequisite: IHE640 or consent of instructor. F. Rodriguez.
Production and applications of polymers. Discussion of stabilization and degradation, including processes for recycling and disposal of plastics and related products.

IHE651 Numerical Methods in Chemical Engineering Fall. Credit three hours. Three lectures. G. F. Scheele.
Solution of single and systems of algebraic equations, polynomial approximation, integration, introductory statistics, initial and boundary valued ordinary differential equations, matrix methods, parameter estimation, empirical correlation. Examples are chosen from chemical engineering applications.

IHE671 Process Control Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: IHE430. M. L. Shuler.
Dynamic response of processes and control instruments. Use of frequency response analysis. Laplace

transforms and electronic analogs to predict the behavior of feedback control systems.

[**IHE672 Applied Surface Chemistry** Spring. Credit three hours. Not offered 1975–76.
Aspects of surface chemistry and physics that affect engineering practice. Both equilibrium and dynamic concepts are covered. Topics include capillarity, contact angle phenomena, critical surface tension, absorption, Marangoni effects, coalescence, electrokinetic phenomena and colloid stability, biomaterials and compatability, and heat and mass transfer at mobile interfaces. Both fluid-solid and fluid-fluid interfaces are considered.]

IHE680 Chemical Microscopy Fall. Credit three hours. One lecture, two laboratories. G. G. Cocks.
The use of the light microscope to investigate chemical problems in biological or nonbiological systems. Topics include: the optics of the microscope, types of microscopes (transmission, reflection, polarizing, inference, phase and dark field), the preparation of specimens, qualitative and quantitative analysis, crystallography, and photomicrography.

IHE681 Electron Microscopy Fall. Credit three hours. One lecture, two laboratories. Prerequisite: IHE680 or special permission. G. G. Cocks.
An introductory course designed to teach the student how to use the electron microscope. Topics include: optics of the microscope, the use and maintenance of the microscope, specimen preparative techniques (substrates, particulates, replication, microtomy, electron diffraction, and thinning of metals), photomicrographic techniques, and the interpretation of micrographs.

IHE682 Advanced Chemical Microscopy Offered on demand either term. Credit variable. Prerequisite: IHE680 and/or special permission. G. G. Cocks.
This is primarily a projects course and offers the student the opportunity either to learn more about microscopes and their use or to apply the techniques of microscopy to the investigation of topics or problems of special interest.

IHE683 Laboratory in Optical Crystallography Fall. Credit variable. Two laboratories; lecture given as part of one laboratory. This course partially duplicates the laboratory of IHE321, and is not open to students who have taken that course. It is the normal laboratory for the geological sciences course IGE355, but is open to students who want to take the laboratory only. G. G. Cocks.
An introduction to geometrical and optical crystallography for mineralogists, with instruction in the use of the polarizing microscope. Topics include the optics of the polarizing microscope, and geometrical and optical crystallography.

IHE692, IHE693, IHE694 Research Project Fall and spring. Credit three hours; additional credit by special permission. Prerequisite: IHE430.
Research on an original problem in chemical engineering.

IHE711 Advanced Chemical Engineering Thermodynamics Fall. Credit three hours. Three lectures. Prerequisite: IHE312 or equivalent. R. York.
Application of general thermodynamic methods to advanced problems in chemical engineering. Evaluation, estimation, and correlation of properties; chemical and phase equilibrium.

[**IHE712 Reactor Design** Spring. Credit three hours. Not offered 1975–76.
Effects of heat transfer, diffusion, and nonideal flow on reactor performance. Optimum design for complex reactions. Analysis of current literature on topics such as partial oxidation, catalytic cracking, hydrogenation, and polymerization.]

IHE713 Advanced Chemical Engineering Kinetics Fall. Credit three hours. Three lectures. Prerequisite: IHE410 or equivalent. P. Harriott.
Fundamentals of homogeneous reactions and heterogeneous catalysis. Development of kinetic rate expressions for homogeneous and heterogeneous systems. Effects of diffusion and temperature gradients. Problems in interpretation of data for real systems.

IHE714 Diffusion in Membranes and Porous Solids Spring. Credit two hours.
Theories for diffusion of gases and liquids in porous solids, porous membranes, and dense membranes. Problems in analysis and correlation of experimental results.

IHE731 Advanced Transport Phenomena Spring. Credit three hours. G. F. Scheele.
An integrated treatment of momentum, mass and heat transfer. Molecular transport, the equations of change, viscous laminar flow of Newtonian and non-Newtonian fluids, perfect fluid theory, boundary layer theory, unsteady-state transfer, penetration theory, models of mass and heat transfer, flow stability, turbulent transport, simultaneous heat and mass transfer, applications to industrial operations.

IHE751 Methods of Chemical Engineering Analysis Fall. Credit three hours. May be taken by undergraduates with the permission of the instructor. K. B. Bischoff, J. F. Stevenson.
Methods of mathematical analysis of direct applicability in thermodynamics, transport phenomena, and chemical reactor design.

IHE790 Seminar Fall and spring. Credit one hour.
General chemical engineering seminar required of all graduate students majoring in the Field of Chemical Engineering.

IHE891, IHE892, IHE893 Thesis Research Either term.
Thesis research for the Master of Science degree in chemical engineering.

IHE991, IHE992, IHE993, IHE994, IHE995 Thesis Research Either term.
Thesis research for the Ph.D. degree in chemical engineering.

Civil and Environmental Engineering

The courses in civil and environmental engineering are listed under the following headings: *Professional Practice; Environmental Sensing, Measurement, and Evaluation; Environmental Engineering* (Environmental Quality Engineering, Fluid Mechanics and Hydrology, Public and Environmental Systems Engineering, Transportation, and Water Resources Planning and Analysis); and *Structural Engineering* (Analysis, Behavior, and Design; Structural Materials; and Soil Mechanics and Foundations).

Professional Practice

IIK502 Civil and Environmental Engineering Practice On demand. Credit three hours. Prerequisite: fourth year or graduate standing. Staff.
Analysis of large engineering works, planning and organizing engineering and construction projects, professional practice, feasibility evaluations, financial justification of projects, social and political implications. The case method is used extensively.

IIK510 Civil and Environmental Engineering Design Project I Fall. Credit one or two hours. Normally required for students in the M.Eng. (Civil) program. Staff.
First term of a two-term sequence. Design of a major civil engineering project embodying several aspects of civil engineering. Planning and part of preliminary design to be accomplished in the fall term; remainder of preliminary design and final design in the winter intersession. Projects to be carried out by students working under the direction of a faculty project coordinator.

IIK511 Civil and Environmental Engineering Design Project II Spring. Credit three hours. Prerequisite: IIK510. Normally required for students in the M.Eng. (Civil) program. Continuation of IIK510. Staff.

IIK520–521 Professional Practice in Engineering Fall: IIK520. Spring: IIK521. Credit three hours a term. Required of each candidate for the M.Eng. (Civil) degree. Enrollment limited to candidates for the professional Master of Engineering degrees.
The objective is to introduce the student to the business, professional, and managerial aspects of the professional practice of engineering. Emphasis is placed upon legal, financial, social, and ethical aspects. Other topics include: personnel management, labor relations, professional registration and organizations, and engineering communications.

IIK801 Thesis The thesis gives the student an opportunity to work out a special problem or make an engineering investigation, to record the results of his or her work, and to obtain academic credit for such work. Registration for the thesis must be approved by the professor in charge at the beginning of the semester during which the work is to be done. Topics are selected by agreement between the professor and the student. They are intended to be pursued under the immediate direction of the professor in charge, the student usually being free from the restriction of the classroom and working either independently or in conjunction with others pursuing the same topic.

Environmental Sensing, Measurement, and Evaluation

IIA153 Principles of Navigation Fall. Credit four hours. Three lectures, discussion period, and project work. A. J. McNair.
Coordinate systems, chart projections, navigational aids, instruments, compass observations, tides and currents, soundings. Celestial navigation: time, spherical trigonometry, motion of the stars and sun, star identification, position fixing, use of Nautical Almanac. Electronic navigation.

IIA380 Engineering Surveying and Evaluation Fall. Credit three hours. Two lectures, one laboratory. Intended for juniors as an introductory course. Staff.
Surveying: basic principles of geometric measurements, including errors and adjustment; modern surveying instruments and procedures for measuring and laying out angles, distances, areas, and volumes; use of coordinate systems and modern mapping methods for the acquisition and display of earth resources data. Evaluation: significance of the several components of the physical environment in engineering projects; assessment of information about these components from maps, airphotos, and ground data; land inventory systems.

IIA651 Field Astronomy On demand. Credit two hours. One lecture, one laboratory (including evening observations). Prerequisite: IIA380, or equivalent with consent of instructor. G. B. Lyon.
Theory and practice in the determination of position (latitude and longitude) of points and directions (azimuth) of lines on the earth by observation of celestial bodies. Topics include: stellar and geographic coordinate systems, use of star catalogs, measurement of time, and pertinent observation and computation procedures.

IIA652 Geometric Data Adjustments On demand. Credit three hours. Three lecture-discussion periods. Prerequisites: Mathematics 293 and IIA380 and IOR260, or equivalent with consent of instructor. G. B. Lyon.
Theory and practice of the adjustment of geometrically constrained observations with emphasis upon surveying applications. Topics include: error theory, minimum variance and other bases for adjustment of observations, and the evaluation of the precision of the results of such observations.

IIA656 Boundary Surveys Spring. Credit three hours. Three lectures. Prerequisite: IIA380 or Agricultural Engineering 221, or equivalent with consent of instructor. A. J. McNair.

The legal principles controlling the location of land boundaries. Topics include: historical development and methods of original land surveys; metes and bounds, U.S. public land and other subdivisions; boundary retracement and restoration of lost property corners, U. T. M. and State Plane Coordinate Systems; mineral land surveys; riparian and littoral rights; and the responsibilities of licensed surveyors.

IIA661 Photogrammetry Fall. Credit three hours. Two lectures, one laboratory. Prerequisite: consent of instructor. A. J. McNair.
Principles of terrestrial, aerial, and space photogrammetry, geometry of a photograph; tilt and relief displacements; parallax distortions; control requirements; flight planning. Stereo plotting; relative and absolute orientation; use of Bausch and Lomb Balplex, Wild A-9 Autograph, and Zeiss stereometric camera including Terragraph plotter. Geometry of remote sensors.

IIA662 Analytic Aerotriangulation Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: IIA661. A. J. McNair.
Coplanarity and colinearity mathematical equations for performing spatial solutions for resection and orientation for single photo, stereo pair, triplet, strip, sub-block, and block coverages of various types of surfaces for which positioning is sought. Stereogram assemblage and coordinate transformation of strip and block coordinates. Solutions of large rectangular matrices in photogrammetry.

IIA671 Geodesy Spring. Credit three hours. Three lectures. Prerequisite: consent of instructor. A. J. McNair.
The figure of the earth and the precise determination of position on or near the earth's surface. Fundamentals of geometric geodesy, physical geodesy, satellite geodesy, and map projections.

IIA685 Physical Environment Evaluation Fall. Credit three hours. Two lectures, one laboratory. Prerequisite: consent of instructors. T. Liang, D. J. Belcher.
A study of physical environment and resources factors affecting engineering and planning decisions and methods of evaluating these factors. Physical factors include the climate, soil and rock conditions, and water resources in different parts of the world. Evaluation methods include field reconnaissance, interpretation of meteorological, topographic, geological, and soil maps, and use of aerial photography, engineering data, and subsurface exploration records. Display and presentation.

IIA686 Advanced Physical Environment Evaluation Spring. Credit three hours. Two lectures, one laboratory, Prerequisite: IIA685 or IIA687 or consent of instructors. T. Liang, D. J. Belcher.
A study of physical environment and resources by use of aerial photography and other remote sensing methods. Conventional photography, sequential photography, multiple spectral photography, space photography, and infrared thermal and radar imagery. Evaluation of environment is directed to the planning of engineering and development projects in general, with some emphasis on those related to special climatic regions such as arctic, tropical, humid, and arid regions.

IIA687 Analyses and Interpretation of Aerial Photographs Fall and spring. Credit three hours. Two lectures, one laboratory. Prerequisite: consent of instructors. Preregistration required. The student is expected to pay the cost of field trips, and aerial photographs for use in a term project—approximately $15. D. J. Belcher, T. Liang.
Methods of identification of a broad spectrum of soils, rocks, and drainage conditions; the significance of vegetative and cultural patterns of the world. Natural resources inventories and specific fields of application are emphasized.

IIA688 Advanced Interpretation of Aerial Photographs Fall and spring. Credit three hours. Prerequisite: IIA687 or consent of instructors. D. J. Belcher, T. Liang.
Lectures and team projects in laboratory and field. Facilities include material for city-regional planning, soil mapping, conservation, ground and surface water, and civil engineering projects.

IIA689 Remote Sensing Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: consent of instructor. T. Liang.
Fundamentals of sensors and sensing in the electromagnetic spectrum. Photographic sensing will be discussed; however, emphasis will be placed on nonphotographic forms. Coverage will include sensors, sensor and ground data acquisition, data geometry, analysis and interpretation, and mission planning.

IIA691 Design Project On demand. Credit one to six hours. Staff.
Design problems, frequently associated with the Master of Engineering program.

IIA692 Research On demand. Credit one to six hours. Staff.
For students who wish to study one particular area in depth. The work may take the form of a laboratory investigation, field study, theoretical analysis, or the development of design precedures.

IIA693 Seminar On demand. Credit one hour. Staff.
Presentation and discussion of technical papers and current research in the general field or one of its specialized fields.

IIA694 Special Topics On demand. Credit one to six hours. Staff.
Supervised study in small groups on one or more special topics not covered in the regular courses. Special topics may be of a theoretical or applied nature.

IIA696 Seminar in Remote Sensing Credit one hour. T. Liang.
Presentation and discussion of current research and development in remote sensing. Lectures by Cornell

staff members and invited specialists from government and industry.

Environmental Engineering

Environmental Quality Engineering

IIE301 Environmental Quality Engineering Spring. Credit three hours. Two lectures, one laboratory, computation or recitation period. Prerequisite: IIC301. J. J. Bisogni, A. W. Lawrence.
Introduction to air, water, and solid waste aspects of environmental quality engineering with emphasis on water quality control concepts, theory, and methodology. Elementary analysis and design applicable to water supply and distribution systems, and systems for wastewater and storm water collection and disposal. Introduction to the processes fundamental to water and wastewater treatment. Effects of wastewater effluents on natural waters.

IIE602 Water-Quality Control Engineering Fall. Credit three hours. Three lecture-recitations. Prerequisite: IIE301 or consent of instructor. V. C. Behn, C. D. Gates.
Biological, chemical, and physical fundamentals underlying water and wastewater treatment and their application to the analysis and design of processes for the treatment of natural waters and of wastewaters. Principles and analysis of methods applicable to the disposal of residuals after treatment.

IIE603 Environmental Quality Engineering Laboratory Spring. Credit three hours. One lecture, two laboratories. Enrollment limited to twelve students. Prerequisite: IIE602. V. C. Behn.
Laboratory methods and experiments of interest in assessing the quality of natural waters and in the measurement and control of municipal and industrial wastewaters and solid wastes.

IIE610 Chemistry of Water and Wastewater Fall. Credit three hours. Three lecture-recitations. Prerequisites: one year of college chemistry and consent of instructor. J. J. Bisogni, C. D. Gates.
Principles of physical, organic, inorganic, and biochemistry applicable to the understanding, design, and control of water and wastewater treatment processes and to reactions in receiving waters.

IIE611 Aquatic Chemistry Spring. Credit three hours. Three lectures. Prerequisites: IIE610 and Chemistry 287 – 288. J. J. Bisogni.
Chemical equilibrium in natural aquatic systems, including water and wastewater treatment systems. Chemical thermodynamics, acid-base systems, oxidation-reduction systems, coordination chemistry, solid-liquid-gas interfaces with regard to precipitation, dissolution, and adsorption. Chemical-biological interfaces in natural systems.
Emphasis on phenomena, mathematical solution of chemical equilibrium, and application to engineering management of water quality.

IIE613 Biological Phenomena and Processes Fall. Credit four hours. Three lectures, one laboratory. Prerequisite: IIE602 or equivalent and concurrent registration in IIE610. A. W. Lawrence.
Theoretical and engineering aspects of biological phenomena and processes applicable to the removal of impurities from water, wastewater, and industrial wastes and to their stabilization in receiving waters. Pertinent microbiological principles, biological oxidation kinetics, and eutrophication. Analysis and design of biological treatment processes. Laboratory studies of pertinent phenomena and processes.

IIE614 Chemical and Physical Phenomena and Processes Spring. Credit four hours. Three lectures, one laboratory. Prerequisites: IIE610 and IIE613. A. W. Lawrence.
Theoretical and engineering aspects of chemical and physical phenomena and processes applicable to the removal of impurities from water, wastewater, industrial wastes, and receiving waters; reaction kinetics, transfer and dispersion phenomena, and fine particle mechanics. Analysis and design of conventional and advanced treatment and disposal processes. Laboratory studies of pertinent phenomena and processes.

[**IIE620 Environmental Quality Control** Spring. Credit three hours. Three lecture-discussions. Prerequisite: senior or graduate student status and consent of instructor. Not offered 1975–76.
Environmental pollution problems: their nature, causes, and effects. Concepts, phenomena, and methodology fundamental to protection of the air-land-water environment. Engineering, technological, and regulatory aspects of water quality control, air quality control, and solid waste management.]

IIE630 Solid Waste Management (Same as Agricultural Engineering 675.) Spring. Credit three hours. Three lectures, reports. Prerequisite: consent of instructor. V. C. Behn.
Study of municipal, industrial, and agricultural solid wastes. Emphasis on waste characteristics, methods of treatment and disposal, and interrelationships with air, water, and land environment. Discussion of regulatory and cost considerations, and economic and political aspects. Intended primarily for graduate students, but open to qualified undergraduates.

IIE631 Industrial Waste Engineering (Same as Agricultural Engineering 676.) Spring. Credit three hours. Three lecture-discussions; field trips. Prerequisite: prior knowledge of wastewater treatment principles. C. D. Gates.
Characterization of liquid, gaseous, and solid industrial wastes; their effects on receiving media. Treatment and disposal alternatives. Legislative and regulatory aspects of industrial waste control; industrial effluent guidelines and limitations. Waste sampling and analysis; effluent monitoring. Wastewater reclamation and recycling. Case studies of industrial waste control in several specific industries, including energy production. Each student will make an in-depth study of and prepare a report on an industry or a waste problem of his or her choice.

IIE633 Environmental Quality Fall; spring on demand. Credit three hours. Three lecture-

discussions. Field trips. Prerequisite: upperclass or graduate student status. L. B. Dworsky.
An introduction to environmental quality and pollution problems: their nature, causes, and control. Man's interaction with the air-land-water resource. Engineering and regulatory aspects of environmental quality management, with emphasis on control of air quality, water quality, and solid wastes.

IIE634 Air Quality Control Spring. Credit three hours. Three lecture-discussions. Prerequisite: upper-class or graduate student status. C. D. Gates.
An introduction to air quality and air pollution problems. Sources, natures, and effects of specific air pollutants; their dispersion and interactions in the atmosphere. Air quality standards, regulations, and legislation. Air quality control methods and technology.

IIE791 Design Project in Sanitary Engineering On demand. Credit variable. Prerequisite: IIE301 or IIE602 or equivalent. Staff.
The student will elect or be assigned problems in the design of water and wastewater treatment processes or plants; wastewater disposal systems; water quality control systems; water resource development or management systems; or laboratory projects of special interest.

IIE792 Sanitary Engineering Research On demand. Credit variable. Prerequisites will depend on the particular investigation to be undertaken. Staff.
For the student who wishes to study a special topic or problem in greater depth than is possible in formal courses.

IIE693 Environmental Quality Engineering Colloquium Fall and spring. Credit one to two hours. Required of graduate students majoring or minoring in sanitary engineering. Open to undergraduates with consent of the instructor.
Presentation and discussion of current topics and problems in sanitary engineering and environmental quality engineering.

IIE794 Special Topics in Sanitary Engineering On demand. Hours and credit variable. Staff.
Supervised study in special topics not covered in formal courses.

Fluid Mechanics and Hydrology

IIC301 Fluid Mechanics Fall. Credit three hours. Three lecture-recitations. J. A. Liggett.
Fluid properties, hydrostatics, the basic equations of fluid flow, potential flow, dimensional analysis, flow in conduits, open channel flow.

IIC302 Hydraulic Engineering Spring. Credit three hours. Two recitations, one laboratory. Prerequisite: IIC301. P. J. Murphy.
Free surface and pipe flow, fluid meters and measuring devices, hydraulic machinery, unsteady flow, waste heat discharges into lakes and rivers, applications of fluid mechanics. Laboratory will include a number of experiments in fluid mechanics and hydraulic engineering.

IIC612 Experimental and Numerical Methods in Fluid Mechanics On demand. Credit two hours. Prerequisite: IIC302 or consent of instructor. J. A. Liggett.
Primarily laboratory, for undergraduates and graduates; may be repeated for credit upon permission of the instructor. Emphasis is on planning and conducting laboratory and field experiments and numerical computation.

IIC615 Advanced Fluid Mechanics I Fall. Credit three hours. Three recitations. Prerequisite: IIC301. P. J. Murphy.
Introduction to vector and tensor notation. The equations of conservation of mass, momentum, and energy from a rigorous point of view. Similitude and modeling potential flow including circulation, vorticity, conformal mapping, and hodograph methods.

IIC716 Advanced Fluid Mechanics II Spring. Credit three hours. Three recitations. Prerequisite: IIC615. P. J. Murphy, J. A. Liggett.
Exact solutions to the Navier-Stokes equations, the laminar and turbulent boundary layers, turbulence, introduction to non-Newtonian flow, and other topics.

IIC617 Free-Surface Flow Spring. Credit three hours. Three recitations. Prerequisite: IIC615 or IIC618, or consent of instructor. J. A. Liggett.
The formulation of the free-surface equations and boundary conditions. Shallow water theory and the theory of characteristics. Unsteady and two-dimensional flow in open channels.

IIC618 Dynamic Oceanography Fall. Credit three hours. Prerequisite: elementary fluid mechanics. P. L.-F. Liu.
The statics and dynamics of oceans and lakes. Currents in homogeneous and stratified bodies of water. Tides, seiches, waves, and tsunamis. Turbulence and diffusion.

IIC631 Wave Hydrodynamics in Coastal Engineering Spring. Credit three hours. Prerequisite: IIC301, IIC618 also recommended. P. L.-F. Liu.
Problems in waves and currents of interest to coastal and ocean engineers. Topics chosen from the following areas: Ray theory of refraction. Scattering of small amplitude waves by breakwaters or submerged and floating bodies. Harbor response to incident waves. Transient waves; tsunami propagation. Finite amplitude effects in shallow water waves. Boundary layers in water waves; damping and mass transport current. Implication of mass transport on the shoreline processes.

IIC632 Sediment Transport Spring. Credit three hours. Prerequisite: IIC302 or consent of instructor. P. J. Murphy.
Description of the movement of solid particles in open channels. Particle mechanics, the saltation process, turbulent dispersion, erosion and deposition of channel beds, suspended sediment transport, bed transport processes, bed forms, measurement techniques. Application to canals, the dynamics of natural streams, river regulation, and dispersion of pollutants.

IIC621 Flow in Porous Media Spring. Credit three hours. Prerequisite: IIC301; IIC615 also recommended. W. H. Brutsaert.
Fluid mechanics of flow through porous solids. The general equations of single phase and multiphase flow and the methods of solving the differential form of these equations. Aquifer hydraulics involving pumping well and streamflow problems; infiltration and ground water recharge; land subsidence; sea water intrusion and miscible displacement; and other steady state and transient seepage problems in fully and partly saturated materials.

IIC609 Descriptive Hydrology Spring. Credit two hours. Intended for non-engineering majors. Prerequisite: consent of instructor. W. H. Brutsaert.
Introduction to hydrology as a description of the hydrologic cycle and the role of water in the natural environment. Topics include precipitation, infiltration, evaporation, ground water, surface runoff, floods, and droughts.

IIC620 Analytical Hydrology Fall. Credit three hours. Prerequisite: IIC301 or equivalent.
W. H. Brutsaert.
Physical and statistical analysis related to hydrologic processes. Hydrometeorology and evaporation. Infiltration and base flow. Surface runoff and channel routing. Linear and nonlinear hydrologic systems analysis. Storage routing and unit hydrograph theory.

IIC691 Project On demand. Hours and credit variable. Staff.
The student may elect a design problem or undertake the design and construction of special equipment in the fields of fluid mechanics, hydraulic engineering, or hydrology.

IIC792 Research in Hydraulics On demand. Hours and credit variable. Staff.
The student may select an area of investigation in fluid mechanics, hydraulic engineering, or hydrology. The work may be either of an experimental or theoretical nature. Results should be submitted to the instructor in charge in the form of a research report.

IIC693 Hydraulics Seminar Spring. Credit one hour. Open to undergraduates and graduates and required of graduate students majoring in hydraulics or hydraulic engineering. Staff.
Topics of current interest in fluid mechanics, hydraulic engineering, and hydrology.

IIC694 Special Topics in Hydraulics On demand. Hours and credit variable. Staff.
Special topics in fluid mechanics, hydraulic engineering, or hydrology.

Public and Environmental Systems Engineering

IIB201 Economic Analysis of the Private Sector (Microeconomics) (Same as Economics 307.) Fall. Credit four hours. Prerequisite: one year of college-level mathematics. Acceptable as a liberal elective for undergraduates in engineering. May be taken for credit in addition to Economics 102, although Economics 102 is not a prerequisite. R. E. Schuler.
Considers the economic behavior of individual households and firms; how individual agents combine under different market structures, including competitive markets, monopoly, and monopsony; and concludes with the theory of distribution and general equilibrium. Most topics will receive both graphical and mathematical treatment. The course is designed to provide students with adequate preparation to take any advanced-level economics course for which Economics 311 is a prerequisite.

IIB202 Economic Analysis of Government (Same as Economics 308.) Spring. Credit four hours. May be taken for credit in addition to Economics 101, although Economics 101 is not a prerequisite. Prerequisites: one year of college-level mathematics and IIB201; or Economics 311.
R. E. Schuler.
A continuation of IIB201. First half: consideration of the welfare implications of various forms of economic organization and the rationale for government intervention in the microeconomy. The theory underlying investment in government projects and environmental programs will be studied. Second half: national economic constraints and aggregate behavior (macroeconomics), together with the impact of government activity on these aggregates. Mathematical as well as graphical tools of analysis are used.

IIB303 Engineering Economics and Systems Analysis Spring. Credit three hours. D. P. Loucks.
Aimed at the junior-senior level. Intended to give the student a working familiarity with the principles and main analytical techniques for reaching decisions about the economic aspects of engineering projects. Concepts of economic decisions; choice among alternatives; break-even and minimum-cost analysis; inventory control; resource allocation and scheduling; concepts of interest, depreciation, and replacement of assets. Decisions under conditions of risk and uncertainty. Introduction to systems analysis as a quantitative basis for investment decisions; optimization, linear programming, critical path scheduling. Not intended for students with substantial background in business economics or methods of operations research.

IIB205 Social Implications of Technology Fall. Credit three hours. S-U grades optional. Open to all Cornell students beyond the freshman year. Acceptable as a liberal elective for undergraduate students in engineering. Students from outside the College of Engineering are invited to take this course.
Some of the issues pertaining to the development, implementation, and assessment of technology. The social, political, and economic aspects of current problems that have important technological components. The technical background will be developed to the extent necessary for an intelligent consideration of policy alternatives. Students will be required to do extensive reading and may be required to participate in case studies or write a term paper.

IIB615 The Law and Environmental Control Fall. Credit four hours. Prerequisite: consent of instructor. Designed for seniors and graduate students.
An introduction to the structure and operation of the legal system and an investigation of the manner in which that system may handle environmental problems. The interaction of law and science, regional problems and political jurisdictional boundaries (the interstate compact), the police power of the states, statutory law and case law, the judicial function, the nature and functions of the administrative agencies, environmental regulation, recent environmental case law.

IIB616 Seminar in Technology Assessment Spring. Credit three hours. Prerequisite: consent of instructor, based on a showing of adequate background.
An interdisciplinary seminar dealing with the social consequences of future technological development and means by which technology can be guided in socially beneficial directions. Topics include: governmental institutions, such as the Congress, courts, and regulatory agencies, and the manner in which they handle technical problems; economic considerations and the role of the market; the planning process (prediction, role of normative considerations, creation and evaluation of alternative courses of action, and feedback considerations); existing assessment mechanisms and institutions in the private and public sectors, and proposed new structures; opportunities for public participation. Student-faculty task forces will organize to undertake projects exploring aspects of technology assessment theory and methodology, do case studies, perform simple assessments, or investigate questions pertaining to the design and functioning of institutions to perform such tasks.

IIB617 Public Systems Analysis I Fall. Credit three hours. D. P. Loucks.
An introduction to the philosophy and techniques of systems analysis as applied to the public sector. Discussion and comparison of various techniques that have been traditionally associated with public systems analysis: economics (primarily marginal analysis and welfare economics), operations research (primarily linear, nonlinear, and dynamic programming), decision analysis, cost-benefit and cost-effectiveness analysis, and engineering economics (present value and rate-of-return evaluation). The emphasis is on integrating these approaches in the context of specific public sector applications.

IIB618 Public Systems Analysis II Spring. Credit three hours. Prerequisite: one of the following (which may be taken concurrently); IIB303, IOR320, IOR622, Agricultural Engineering 475, or consent of instructor. IOR260 and IIB260 recommended but not required. C. A. Shoemaker.
Mathematical public systems models which integrate economic, environmental and social considerations to develop desirable managements programs. Course emphasis will be on applications in the following areas: public health, long-range global planning *(Limits to Growth),* water resources, macroeconomic policy. Methodology will include simulation and mathematical programming.

IIB619 Environmental Systems Analysis On demand. Credit three hours. Prerequisite: IIB618. D. P. Loucks.
Application of systems analysis, environmental engineering, and economics to environmental quality management systems. Evaluation of public policy alternatives for air, land, and water quality control and for reducing the material and thermal and acoustical energy wastes released into the environment. Development of deterministic and stochastic models for steady-state and dynamic conditions.

IIB747 Environmental Policy Analysis On demand. Credit three hours. Prerequisite: IOR260, IIB618, or equivalent, or consent of instructor. D. P. Loucks.
Current research topics concerning the application of economic and simulation techniques to the definition and evaluation of public policy alternatives for managing air, land, and water resources and the material and energy wastes released into the environment. The influence of technologic, economic, and political uncertainty will be emphasized. Each student will be expected to select a particular environmental management problem and structure models or methods for analyzing alternative solutions.

IIB651 Environmental Quality Management in Aquatic and Agricultural Ecosystems Spring. Credit three hours. Prerequisite: one of the following: IIB303, IOR320, IOR622, Agricultural Engineering 475; or consent of instructor. Biological Sciences 361 or 261 strongly recommended. C. A. Shoemaker, D. A. Haith.
The application of ecological principles, mathematical modeling, and optimization techniques to the management of aquatic and agricultural ecosystems. Applications include nutrient management, eutrophication, integrated pest management, and land use effects on water quality.

IIB780 Environmental Contrl Workshop On demand. Credit one to three hours by arrangement with instructor. W. R. Lynn.
Students interested in research topics dealing with control of the environment (with special emphasis on biological and ecological aspects) are encouraged to participate in this workshop. Topics discussed in previous workshops include human population control, control of pest and parasite populations, study of species' strategic use of food supply, control of populations by use of predators, and host-parasite systems. Additional topics will be developed.

IIB791 Environmental Systems Analysis Design Project On demand. Credit variable. Prerequisite: consent of instructor. May extend over two semesters. Staff.
Design of feasibility study of public or environmental systems, supervised and assisted by one or more faculty advisers. Individual or group participation. Final report required.

IIB792 Environmental Systems Analysis Research On demand. Credit variable. Prerequisite: consent of instructor. Preparation must be suitable to the investigation to be undertaken. Staff.

Investigations in depth of particular public or environmental systems problems.

IIB693 Environmental Systems Analysis Colloquium Either term. Credit one hour.
Lectures in various topics related to environmental or public systems planning and analysis.

IIB794 Special Topics in Environmental Systems Analysis On demand. Credit variable. Staff.
Supervised study, by individuals or small groups, of one or more specialized topics not covered in regular courses.

Transportation

IIF620 Transportation Engineering Fall. Credit three hours. No prerequisites, but some background in microeconomic theory is desirable. G. P. Fisher.
Introduction to the principal technological, economic, and social aspects of modern transportation. A suitable foundation for more advanced transportation courses. Role of transportation in society's economic and social activities, including study of the urban transportation problem and its alleviation, and of institutional structures and current policy issues. Technological and economic characteristics of conventional, emerging, and future forms of transport and terminals. Role of quantitative operational models in improving transportation systems. The transportation planning process, conventional and emerging quantitative models for trip generation, distribution, assignment, and model choice—with some attention to supporting activities such as traffic flow theory and traffic engineering. Human factors, both physiological and psychosocial, that affect the design of transportation components and systems.

IIF621 Urban Transportation Planning I Fall. Credit four hours. Prerequisite for most other courses in transportation area. Prerequisite: a basic microeconomics course. Designed primarily as a first course in transportation planning, leading to one or more of the other transportation courses. It may, however, be taken as an introductory or overview course, in transportation planning. A. H. Meyburg.
The urban transportation problem: its roots, manifestations, and implications; the systems analysis approach to transportation; the demand and supply side of transportation; the urban transportation planning process and its modeling components; generation of alternatives and their evaluation. A laboratory period is designed for study-team research on relevant projects in the area of urban transportation.

[**IIF622 Multivariate Analysis Methods in Transportation** Fall, alternate years. Credit four hours. Prerequisites: IOR260, IOR270, or equivalent; and IIF621, which may be taken concurrently. Intended primarily for graduate students, but qualified seniors may be admitted with consent of instructor. Not offered 1975–76.
Multivariate methods for statistical model building in transportation and other urban systems. Linear and nonlinear regression analysis, weighted regression, canonical correlation, factor analysis, simultaneous equations methods, discriminant analysis, probit analysis, and logit analysis. Applications to transportation demand modeling.]

IIF623 Urban Transportation Planning II Spring, alternate years. Credit three hours. Prerequisite: IIB201, IIB202, IIF621, IIF622; or consent of instructor. Intended primarily for graduate students, but qualified seniors may be admitted with consent of instructor. F. J. Cesario.
Advanced instruction in conventional models of travel demand in transportation studies, including residential and nonresidential trip generation. Fratar, Gravity and opportunity models of trip distribution; trip-end and trip-interchange modal split; network assignment. New methods of travel demand modeling, including spatial distribution theories, "abstract mode" models, and individual behavior theories. The propagation of error in models.

[**IIF624 Transportation Systems Analysis** Spring. Credit three hours. Prerequisite: IOR260, IIF621, IOR622, IOR320, or consent of instructor. A. H. Meyburg. Not offered 1975–76.
Techniques of systems analysis as applied to the physical planning, operation, and financing of transportation facilities. Wherever applicable, mathematical models of transportation processes are used to examine questions related to the development of optimal public policy decisions in the area of transportation. Attention is given to analysis of single and multimodal forms of transportation. Methods of mathematical programming, simulation, and stochastic processes are employed.]

[**IIF640 Traffic Flow Theory** Spring. Credit three hours. Prerequisite: IIF621. Not offered 1975–76.
Study of various mathematical theories of traffic flow. Microscopic models (car following models). Macroscopic models (kinematic wave theory). Stochastic properties of traffic flow at low density. Probability models for traffic lights and optimal control of signalized intersections. Traffic flow on transportation networks. Application to traffic assignment. Traffic network simulation system.]

[**IIF641 Airport Planning and Operations** Spring, alternate years. Prerequisite: IIF621 or consent of instructor. A. H. Meyburg. Not offered 1975–76.
The role of air travel within the overall transportation system, terminal access, location and site selection, terminal design and operations, metropolitan air transit systems, environmental impact of airport location, air traffic flow analysis, air traffic control, aircraft technology.]

IIF643 Design and Planning of Mass Transportation Spring, alternate years. Credit three hours. Prerequisite: IIF621 or consent of instructor. A. H. Meyburg.
A study of mass transportation of the past and present; innovative forms of mass and individual transportation in urban areas. The financing and organization of mass transportation; the "free transit" versus fares dilemma. Planning for mass transportation; special

applications, implementation of plans, planning transportation in new towns.

IIF644 Transportation Systems Evaluation Spring. Credit three hours. Prerequisites: IIF621 and a basic microeconomics course. F. J. Cesario.
Economic evaluation techniques; measures of effectiveness; cost-effectiveness evaluation; definition of goals, objectives, and criteria for transportation planning; impact analysis and evaluation.

IIF791 Transportation Design Project On demand. Credit variable. Prerequisite: consent of instructor. May extend over two semesters. Staff.
Design or feasibility study of transportation systems, supervised and assisted by one or more faculty advisers. Individual or group participation. Final report required.

IIF792 Transportation Research On demand. Credit variable. Prerequisite: consent of instructor. Preparation must be suitable to the investigation to be undertaken. Staff.
Investigation in depth of particular public systems problems.

IIF793 Transportation Colloquium Either term. Credit one hour.
Lectures in various topics related to transportation planning and analysis.

IIF794 Special Topics in Transportation On demand. Credit variable. Staff.
Supervised study, by individuals or small groups, of one or more specialized topics not covered in regular courses.

Water Resources Planning and Analysis

IIH615 Water Resources Problems and Policies Fall. Credit three hours. Lecture-discussion. Prerequisite: consent of instructor. Intended primarily for graduate engineering and nonengineering students but open to qualified upperclass students. L. B. Dworsky.
A comprehensive approach to water resources planning and development. Historical and contemporary perspectives of water problems, organization, and policies.

IIH616 Water Resources Planning Seminar Spring. Credit three hours. Prerequisite: IIH615 or consent of instructor. L. B. Dworsky.
The concepts, processes, and techniques of regional, multipurpose river basin planning and development. The case study method, including the preparation of an integrated, comprehensive report for the study area.

IIH718 Water Resource Systems Fall or spring. Credit three hours. Prerequisite: any introductory course in systems analysis, or consent of instructor. D. P. Loucks.
Application of economics, engineering, and mathematical optimization and simulation models to river basin planning and regional development, hydropower and irrigation planning, reservoir operation, flow augmentation for quality control, watershed runoff, and other multiobjective, multipurpose water resources planning and management problems. Students will have the opportunity to improve their modeling skills and solve deterministic and probabilistic models for steady-state or dynamic conditions. Review of current literature.

IIH731 Water and Land-use Policy Analysis On demand. Credit three hours. Prerequisite: consent of instructor. D. P. Loucks.
Current research topics concerning the application of mathematical planning techniques, economic theory, and regional science to the definition and evaluation of alternative water and related land-use development policies. Emphasis on multiple objectives and policy instruments that affect flood plain development. Review of current literature. A graduate research seminar for students who have a background in systems analysis and other applicable disciplines.

Structural Engineering

Analysis, Behavior, and Design

IIG301 Structural Engineering I Fall. Credit four hours. Three lectures, one two-hour period; evening examinations. Prerequisite: Mechanics IAK221. J. F. Abel, A. H. Nilson.
Introduces the fundamental concepts of structural engineering analysis and behavior. First course in a four-course sequence of structural theory, behavior, and design. Structural planning, loads, structural form, analysis of statically determinate systems, approximate analysis of statically indeterminate systems. Introduction to the behavior of simple steel and concrete members.

IIG302 Structural Engineering II Spring. Credit four hours. Three lectures, one two-hour period; evening examinations. Prerequisite: IIG301. R. H. Gallagher.
Presents the fundamentals of the calculation of displacements and the analysis of statically indeterminate structures, and uses these as the basis for further understanding of structural behavior and design. Virtual work; flexibility and stiffness methods, including moment distribution; plastic behavior; analysis for moving loads. Applications to steel and concrete structures.

IIG303 Structural Engineering III Fall. Credit four hours. Prerequisites: IIG302 and IIG351 (may be taken concurrently) or consent of instructor. W. McGuire.
Continues the study of the behavior of structures. Behavior and design of steel, concrete, and timber structural elements, connections, and systems.

IIG304 Structural Engineering IV Spring. Credit three hours. Prerequisite: IIG303. R. G. Sexsmith.
The objective is to develop an understanding of the structural design process. Comprehensive design project, drawing on material from previous courses in

structures and materials. Additional topics such as preliminary design, choice of form, shells, models.

IIG305 Structural Behavior Laboratory Spring. Credit two hours. May be taken concurrently with IIG302 or IIG304. R. N. White.
A laboratory course on behavior of structures, utilizing small-scale models. Elastic, inelastic, and nonlinear behavior of structural components and systems, including beams, beam-columns, trusses, frames, grids, plates, and shells in both metal and reinforced concrete. Individual projects.

IIG610 Fundamentals of Structural Mechanics Fall. Credit three hours. Prerequisite: IIG303 (may be taken concurrently). R. H. Gallagher.
This course gives a treatment of topics not normally covered in undergraduate structural mechanics courses but which underlie the respective graduate courses in this department. Includes theory of elasticity, energy principles, plate flexure, theories of failure, elastic and inelastic stress-strain relationships.

IIG711 Stability: Elastic and Inelastic Spring. Credit three hours. T. Peköz.
Analysis of elastic and plastic stability. Determination of buckling loads and post-buckling behavior of columns. Solid and open web columns with variable cross-section. Beam columns. Frame buckling. Torsional-flexural buckling. Lateral buckling of beams. Buckling loads and postbuckling behavior of plates, shear webs, and cylindirical shells. Critical discussion of current design specification.

IIG712 Advanced Structural Analysis Fall. Credit three hours. Three lectures. Prerequisite: IIG302. R. G. Sexsmith.
Stability, determinacy, redundancy of structures. Approximate methods of analysis. Force, displacement, and transfer matrix methods of matrix structural analysis. Development of space frame element equations, including distributed loads and thermal strain effects. Methods of solution; direct and iterative, tridiagonalization, partitioning, and special transformations. Analysis techniques for tall buildings and other special problems.

IIG713 Finite-Element Analysis Spring. Credit three hours. Three lectures. Prerequisite: IIG712. J. F. Abel.
Theoretical and conceptual bases for formulation of finite-element representations in structural analysis. Development of element relationships for structural analysis of plates, shells, and solids. Extension of element- and system-solution techniques to deal with problems in elastic stability, inelastic deformation, finite displacements, dynamic response, and other special behavior mechanisms.

IIG714 Structural Model Analysis and Experimental Methods Fall. Credit three hours. Two lectures, one two-hour period. Prerequisite: indeterminate analysis. R. N. White.
Dimensional analysis and principles of similitude. Direct model analysis, including materials, fabrication, loading, and instrumentation techniques. Basic techniques of experimental stress analysis. Confidence levels for model results. Laboratory projects in elastic behavior and ultimate strength of model structures.

[**IIG715 Probabilistic Concepts in Structural Engineering** Spring, alternate years. Credit three hours. Prerequisite: IIG303. R. G. Sexsmith. Not offered 1975–76.
Introduction to probability concepts pertaining to engineering design and reliability, probabilistic models, inference techniques, decision analysis, stochastic processes; applications in structural safety decisions, including code development, and structural random vibration.]

IIG716 Prestressed Concrete Structures Spring. Credit three hours. Three lectures. Prerequisite: IIG303; IIG304 recommended. A. H. Nilson.
Behavior, analysis, and design of prestressed concrete structures; pretensioning, post-tensioning, precast construction; beams, slabs, composite members, continuous beams and frames, tension and compression members; prestress losses, section efficiency, end zone stresses, deflection analysis, cracking, partial prestressing.

IIG717 Advanced Reinforced Concrete Fall. Credit three hours. Three lectures. Prerequisite: IIG303; IIG304 recommended. A. H. Nilson.
Behavior, analysis, and design of reinforced concrete structures; strength, safety considerations, deflection analysis, crack control, limit analysis, yield line theory, flexure, shear, torsion, axial loads, slenderness effects; beams, columns, slabs, continuous frames, two-way systems, composite construction, deep beams, ground-supported slabs, shear walls, folded plates.

IIG718 Advanced Design of Metal Structures Fall. Credit three hours. Prerequisite: IIG303. W. McGuire.
Behavior and design of steel structures, with emphasis on design applications: single-story frames, plate girders, trusses, and plate structures. Behavior and proportioning of connections.

IIG719 Advanced Behavior of Metal Structures Spring. Credit three hours. Prerequisite: IIG711. W. McGuire.
Behavior of steel beams, beam-columns, and single- and multi-story frames. Torsion and combined torsion and flexure. Critical study of design specifications. Cold-formed steel structures. Fatigue and fracture.

[**IIG720 Shell Theory and Design** Credit three hours. Prerequisites: IIG302 and consent of instructor. Not offered 1975–76.
The fundamentals of practical shell theory. Differential geometry of surfaces; membrane and bending theory of shells; analysis and design of cylindrical shells, polygonal domes, and paraboloids. Application to reinforced concrete roofs and pressure vessels. Introduction to the stability of shells.]

IIG722 Structural Design for Dynamic Loads Fall. Credit three hours. Prerequisites: IIG303, some

computer programming experience, and consent of instructor. P. Gergely.
A broad study of the analysis, design, and behavior of structures subjected to dynamic effects, with emphasis on earthquake-resistant design. Vibration of simple systems; response spectra; numerical, energy, and matrix methods of analysis. Basic seismology. Analysis and design of structures for earthquakes, including inelastic effects. Modern design approaches.

[**IIG732 Optimum Structural Design** Fall, alternate years. Credit three hours. R. H. Gallagher. Not offered 1975–76.
Treats the procedures to be applied in order to design minimum weight or minimum cost structures. Coverage encompasses simplified ideas such as fully-stressed design, classical minimization procedures, and modern methods based on mathematical programming schemes.]

IIG733 Numerical Methods in Structural Engineering Spring, alternate years. Credit three hours. Prerequisites: IIG712 and IAA680 or equivalents and consent of instructor. J. F. Abel.
Numerical analysis, numerical methods, and algorithms related to applications in structural mechanics, structural engineering, and geotechnical engineering. Discussion and comparison of such techniques as weighted residuals, stationary functionals, invariant imbedding, finite differences, and finite elements. Various numerical analysis topics, including solution of linear and nonlinear systems of equations, algebraic eigenvalue problems, numerical integration, approximation of functions, Fourier transforms, and error analysis. Selected algorithms with emphasis on linear equations and eigenvalue problems.

IIG690 Planning of Structural Systems Fall. Credit three hours. Prerequisite: IIG302. Recommended for seniors planning to enter the M.Eng. (Civil) program. T. Peköz.
Functional, structural, and other considerations in the planning and selection of structural systems. Probabilistic description of loading and strength. Preliminary design—estimating overall dimensions and weights, proportioning of members and joints—and optimization. Preliminary analysis of frames, trusses, plates, and shells. Erection, construction, and stress control considerations. Computer structural analysis. Case studies with the participation of practicing engineers.

IIG791 Design Project in Structural Engineering (Meets project requirement for M.Eng. degree for students who cannot enroll in IIK510–511.) Either term. Credit variable. Coregistration in IIG690 during fall term required. Staff.
Comprehensive design project by teams. Formulation of alternate proposals, including economics and planning, for a given situation and complete design of the best alternative. Determination of construction costs and preparation of sketches and drawings. Presentation of designs by oral and written reports.

IIG792 Research in Structural Engineering On demand. Hours and credit variable. Staff.
For students wishing to pursue one particular branch of structural engineering further than can be done in any of the regular courses. Prerequisite courses depend upon the nature of the work desired. The work may be an investigation of existing types of construction, theoretical work with a view to simplifying present methods of design or proposing new methods, or experimental investigation of suitable problems.

IIG693 Structural Engineering Seminar Fall and spring. Credit one to three hours. Open to qualified seniors and graduate students. Staff.
Preparation and presentation of topics of current interest in the field of structures for informal discussion.

IIG794 Special Topics in Structural Engineering On demand. Hours and credit variable. Staff.
Individually supervised study in one or more of the specialized topics of civil engineering, such as tanks and bins, suspension bridges, towers or movable bridges, which are not covered in the regular courses. Independent design or research projects may also be selected.

Structural Materials

IIG351 Engineering Materials Fall. Credit three hours. Two lectures, one laboratory. F. O. Slate.
Engineering properties of concrete, steel, wood, and other selected structural materials; physicochemical properties of soils, concrete, and bituminous materials. Design characteristics and significance of test results of materials used in engineering works. Extensive laboratory testing and report writing.

[**IIG652 Advanced Plain Concrete** Spring. Credit three hours. Two lectures plus conference. Prerequisite: IIG351 or equivalent. F. O. Slate. Not offered 1975–76.
Topics in the subject of concrete, such as history of cementing materials, air entrainment, light-weight aggregates, petrography, durability, chemical reactions, and properties of aggregates. Relationships among internal structure, physical properties, chemical properties, and the mechanical properties of interest to the design and construction engineer.]

[**IIG653 Structure and Properties of Materials** Spring, alternate years. Two lectures plus conference. Open to graduate students in engineering or the physical sciences or to undergraduates by consent of the instructor. F. O. Slate. Not offered 1975–76.
Internal structure of materials ranging from the amorphous to the crystalline state. Forces holding matter together versus forces causing deformation and failure. Correlation of the internal structures of materials with their physical and mechanical properties. Applications to various engineering materials.]

[**IIG757 Civil and Environmental Engineering Materials Project** On demand. Credit one to six hours. F. O. Slate. Not offered 1975–76.
Individual projects or reading and study assignments involving engineering materials.]

[**IIG654 Low-Cost Housing Primarily for Developing Nations** Spring, alternate years. Credit three hours. Two lectures plus conference. F. O. Slate. Not offered in 1975–76.
A multidisciplinary course involving faculty members from the College of Architecture, Art, and Planning, and the College of Human Ecology. Students will do intensive study, usually in their own discipline, for a term project, while also being introduced to problems and approaches of other disciplines. For engineers, the primary purpose is to investigate the technological aspects of the subject, and other aspects that influence technological decisions, such as cultural and economic factors. Typical technological aspects are indigenous materials, structural systems, construction, maintenance, and effects of the physical environment. Coverage is from agrarian-rural to industrial-urban.]

IIG655 Low-Cost Housing for Developing Nations —Workshop for Physical Planning, Site Selection, and Design Registration also available as a course in architecture. Spring, alternate years. Credit three hours. Prerequisite: consent of instructor. F. O. Slate.
Intended for a mixed class of advanced civil engineering and architecture students. Discussions and workshop sessions covering physical planning, site selection, and detailed design of individual structures and groupings of structures. Opportunity for choice of appropriate materials and detailed design of structural members.

Soil Mechanics and Foundations

IID301 Elements of Soil Mechanics Spring. Credit three hours. Two lectures, one laboratory. D. A. Sangrey.
Soil properties, chemical nature, particle size distribution, Atterberg limits, permeability, principle of effective stress, compressibility, shear strength, the consolidation process. Introduction to bearing capacity, earth pressure, slope stability, settlement, seepage and the solution of practical problems. Laboratory tests for the measurement of soil properties.

IID606 Engineering of Foundations and Earth Retaining Structures Fall. Credit three hours. Two lectures, one two-hour period. Prerequisite: IID301. J. N. Kay.
Mechanics and development of earth pressure in relation to soil properties and deformation. Design of retaining walls and bulkheads. Principles of bearing capacity, stress distribution, and settlement. Soil exploration techniques; design of shallow and deep foundations; design of footing, raft, caisson, and pile foundations. Problems of construction and stability of excavations. Influence of ground-water flow on walls, foundations, and excavations.

IID610 Engineering Properties of Soils Fall. Credit three hours. Three lectures. Prerequisite: IID301. Undergraduates must have a grade of B or better in IID301 or consent of instructor. D. A. Sangrey.
Natural environments in which soils are formed; the chemical and physical nature of soils. Principle of effective stress; stress-strain relationships; shear strength and compressibility of natural geotechnical materials. Sensitivity, partial saturation, organic and frozen materials, anisotropy. Primary and secondary consolidation. Soil properties influencing permeability.

IID616 Slope Stability: Earth and Rockfill Dams Spring. Credit three hours. Two lectures and one two-hour period. Prerequisite: IID301. D. A. Sangrey, J. N. Kay.
Principles of stability for earth and rock slopes, effects of pore water pressure, short- and long-term stability, problems of drawdown, analysis of landslides and dam stability, principles of earth and rockfill dam design, internal pore water pressures and drainage, filters, relief wells, foundation problems, grouting, cut-offs, control, and instrumentation.

IID712 Graduate Soil Mechanics Laboratory Spring. Credit three hours. Prerequisite: IID610. J. N. Kay, D. A. Sangrey.
Laboratory measurement of soil properties: classification tests, direct shear tests, triaxial tests for the measurement of pore water pressure, strength parameters. Pore pressure dissipation tests. Relationship of laboratory tests to field behavior.

IID714 Advanced Geotechnical Engineering Fall. Credit three hours. Three lectures. Prerequisite: IID606 or equivalent. J. N. Kay.
A review of more intensive detail of topics covered in IID606, with emphasis on recent developments in soil-structure interaction problems. Topics include theories of bearing capacity and settlement determination for shallow and deep foundations; the response to horizontal loading of pile groups, retaining walls, and excavation supports; buried conduits and tunneling in soft ground.

IID715 Soil Dynamics Fall. Credit three hours. Three lectures. Prerequisite: consent of instructor. D. A. Sangrey.
Introduction to principles of the vibration of simple systems under harmonic and transient loading. Energy propagation by waves through solid and layered systems. Detailed consideration of the response of soils to dynamic and repeated loading, and the measurement of these characteristics. Analytical models of simple foundations on elastic media and design methods. Analysis and design examples.

IID718 Case Studies in Soil Mechanics and Foundation Engineering Spring. Credit three hours. Prerequisite: IID610. D. A. Sangrey, J. N. Kay.
Study of real engineering problems of various types, importance of the geological environment in recognizing the nature of field problems, application of mechanics and soil properties to obtain engineering solutions. Preparation of engineering reports.

[**IID631 Pavement Design and Construction** On demand. Credit three hours. Two lectures, one laboratory. Prerequisite: IID301 or consent of instructor. Not offered 1975–76.
Part I: subgrade evaluation, compaction, drainage and frost action, stabilization. Part II: aggregates,

bituminous materials, evaluation of flexible pavement components, design and construction of flexible pavement structure. Part III: design and construction of rigid pavements.]

IID632 Highway Engineering (Same as Agricultural Engineering 491.) Offered upon sufficient demand, usually in the fall term. Credit three hours. Prerequisite: consent of instructor. Principally directed study and individual or team investigations with one 2½-hour session per week, to be arranged.
Emphasis is on secondary roads in study of: economic considerations in road system improvement, road improvement planning and programming, road location and geometric design, engineering soil characteristics and classification, design of roadbed thickness, drainage, stabilization methods and materials, dust palliatives, wearing surfaces.

IID691 Design Project in Geotechnical Engineering On demand. Credit one to six hours. Staff.
Design problems frequently associated with the Master of Engineering program.

IID792 Research in Geotechnical Engineering
On demand. Credit one to six hours. Staff.
For students who wish to study one particular area of geotechnical engineering in depth. The work may take the form of a laboratory investigation, field study, theoretical analysis, or the development of design precedures.

IID693 Seminar in Geotechnical Engineering
On demand. Credit one to two hours. Staff.
Presentation and discussion of technical papers and current research in the general field of geotechnical engineering or one of its specialized fields.

IID694 Special Topics in Geotechnical Engineering On demand. Credit one to six hours. Staff.
Supervised study in small groups in one or more special topics not covered in the regular courses. Special topics may be of a theoretical or applied nature.

Computer Science

A group of introductory programming courses are scheduled at different times during each term so that students can assemble an appropriate combination of courses. ICS100 is a first course in programming, using PL/1; it is given during the first eight weeks of each semester. ICS101, 102, 104, and 106 are one-credit courses that rely on ICS100 but can be taken the same term. Students can select any number of courses from this group to fit their needs and interests. ICS211 is a foundations course in computers and programming that leads to more advanced courses. Students taking ICS101, 102, 104, or 106 should register for them at the beginning of each term to avoid paying a late registration fee.

ICS100 Introduction to PL/1 Programming
Either term. Credit two hours. Two lectures each week, first eight weeks of term only; three evening quizzes.
Elementary nonmathematical presentation of computer programming, using PL/1. No previous programming experience is assumed.

ICS101 Implications of Computer Technology
Either term. Credit one hour. Two lectures, weeks 9 through 14 only; two evening quizzes. Prerequisite: previous or concurrent registration in ICS100 or equivalent.
A continuation of 100. Overview of computer capability and applications. Discussion of implications of computer technology for society.

ICS102 Introduction to FORTRAN Programming
Either term. Credit one hour. One lecture, weeks 9 through 14 only; two evening quizzes. Prerequisite: previous or concurrent registration in ICS100 or equivalent.
A continuation of 100. Introduction to programming in FORTRAN IV.

ICS104 Introduction to APL Programming
Either term. Credit one hour. S-U grades only. Three lectures, weeks 5 through 8 only; individual laboratory work on the computer; two evening quizzes. Prerequisite: previous or concurrent registration in ICS100 or equivalent.
A continuation of 100. Introduction to interactive programming using APL.

ICS106 Computer Solution of Mathematical Problems Either term. Credit one hour. One lecture, weeks 9 through 14 only; two evening quizzes. Prerequisite: previous or concurrent registration in ICS100 or equivalent.
A continuation of 100. An introduction to numerical computation. Topics are floating point representation, approximations and library functions, and typical algorithms.

ICS105 The Computerized Society Fall. Credit three hours.
The economic, political, and cultural impact of computers and computer-related technology. Seminar style with some lectures to provide background material. Specific topics: computer technology, the cashless society, systems approach to social problems, law enforcement, political campaigns, data banks and privacy, education, machine creativity, and machine intelligence.

ICS211 Computers and Programming Either term. Credit three hours. Two lectures, one laboratory; two evening quizzes. Prerequisite: ICS100 or equivalent programming experience.
An in-depth study of programming with a brief introduction to other areas of computer science. Topics include: analysis of speed of execution, procedures and recursion, proving programs correct, data structures, machine organization. Programming and debugging on a computer are an essential part of this course.

ICS280 Discrete Structures Fall. Credit three hours. Three lectures. Prerequisite: ICS100 or ICS211.
Fundamental mathematical concepts relevant to computer science. Sets, relations, graphs, algebraic structures, partial orderings, lattices, and Boolean algebras. Theoretical and practical applications.

ICS314 Introduction to Computer Systems and Organization Either term. Credit four hours. Two lectures, one laboratory. Prerequisite: ICS211 or equivalent programming experience.
Logical structure of digital computers. Representation of information, addressing mechanisms. Storage and peripheral hardware and their characteristics, the input-output channel, interrupts. Assembly language programming; format and basic instructions, the assembly process, macros. Brief description of operating systems, loaders, interpreters, and compilers. Programming and debugging assembly language programs on a computer are an essential part of this course.

ICS321–322 Introduction to Numerical Analysis Throughout the year. Credit four hours a term. Three lectures. Prerequisites: Mathematics 222 or 294 and knowledge of a programming language such as FORTRAN, ALGOL, or PL/1.
Students solve representative problems by programming appropriate algorithms. Numerical methods for systems of linear equations, eigenvalues, interpolation, differentiation, least squares, Chebyshev solution to discrete and continuous systems, and integration. Numerical solution of differential equations and nonlinear equations in several variables.

ICS410 Data Structures Fall. Credit four hours. Two lectures. Prerequisite: ICS314 or equivalent.
Lists, trees, graphs, and other forms of data structures. List operations including linear lists, circular lists, arrays, and multilinked structures. Binary tree representation, tree traversal, tree enumeration. Garbage collection and dynamic storage allocation. Search and sorting techniques.

ICS411 Programming Languages Fall. Credit four hours. Three lectures. Prerequisite: ICS410 or consent of instructor.
An introduction to the structure of programming languages. Specification of syntax and semantics. Properties of algorithmic, list processing, and string manipulation languages: basic data types and structures, operations on data, statement types, and program structure. Macrolanguages and their implementation. Run-time representation of programs and data. Storage management techniques.

ICS414 Systems Programming and Operating Systems Spring. Credit four hours. Three lectures. Prerequisite: ICS314 or consent of instructor.
The logical design of systems programs with emphasis on multiprogrammed operating systems. Loaders, input-output methods, interacting processes, basic resource control, main storage management, sharing, virtual computer systems, file systems. Case studies. Project involving the design and implementation of a small system.

ICS481–482 Introduction to Theory of Computing I, II Throughout the year. Credit four hours per term. Three lectures. Prerequisites: ICS211 and ICS280 or equivalent mathematics, or consent of instructor.
Introduction to modern theory of computing. Covers results from automata theory, formal languages, effective computability, computational complexity, and analysis of algorithms. Includes finite automata, push-down automata, Turing machines, random access machines, regular sets, context-free languages, parsing algorithms, recursively enumerable sets, unsolvable problems, measures of complexity, data structures, depth first search, graph algorithms, sorting, recursion, dynamic programming, and introduction to reducibilities.

ICS611 Formal Specifications of Programming Languages Fall. Credit four hours. Three lectures. Prerequisite: ICS411 or equivalent.
Formal semantic specification of programming languages including: lambda calculus models, Vienna definition language, and recursive functions. Axiomatic approaches to language definition. Variable-free languages.

ICS612 Translator Writing Spring. Credit four hours. Three lectures. Prerequisite: ICS611 or consent of instructor.
Discussion of the models and techniques used in the design and implementation of compilers. Topics include lexical analysis in translators, compilation of arithmetic expressions and simple statements, specifications of syntax, algorithms for syntactic analysis, code generation and optimization techniques, bootstrapping methods, compiler-compiler systems.

ICS613 Operating Systems Principles Fall. Credit four hours. Three lectures. Prerequisites: ICS414 and ICS611 or consent of instructor.
The structure and organization of operating systems. Emphasis is given to formalizations of the central problems of operating systems design: the relationships of parallel computations and resource allocation techniques. Descriptive schema for parallel processes, process communication. Implementation of process management primitives. Memory management: addressing techniques, relocation, paging, segmentation. Paging algorithms and models for program behavior. Scheduling problems: scheduling of processors, memory transfers, input-output operations. Stochastic models for evaluating scheduling algorithms. Protection: protection mechanisms, models for the protection problem, protection domains, capabilities.

[**ICS615 Machine Organization** Spring. Credit four hours. Three lectures. Prerequisite: ICS314 or consent of instructor. Not offered 1975–76.]

[**ICS616 Operations Research Models for Computer and Programming Systems** Credit four hours. Two lectures. Prerequisites: ICS611 and a course in probability (e.g., Mathematics 371 or Engineering IOD660) or consent of instructor. Not offered 1975–76.]

[**ICS618 Picture Processing** Spring. Credit four hours. Three lectures. Prerequisite: ICS611 or consent of instructor. Not offered 1975–76.]

ICS621–622 Numerical Analysis Throughout the year. Credit four hours a term. Three lectures. Prerequisites: Mathematics 411 and knowledge of a programming language such as FORTRAN, ALGOL, or PL/1, or consent of instructor.
A more thorough treatment of the material of ICS321–322, at a faster pace, and covering additional topics. Emphasis on algorithms appropriate for use with computers.

ICS632 File Processing (Same as Industrial Engineering and Operations Research IOR682.) Fall. Credit four hours. Two lectures. Prerequisite: ICS211.
Concerned with the practical problems of processing large sets of structured data. Topics include problems of file organization, searching, sorting, security, recovery, concurrency. Discussion of languages and operating system services for file processing. Concerned also with techniques for design and programming of large, long-lived, often-changed, and highly reliable systems.

ICS635 Information Organization and Retrieval Spring. Credit four hours. Two lectures. Prerequisite: ICS410 or equivalent.
Introduction to information retrieval. File organization and search algorithms. Statistical analysis and automatic classification of information. Structural language analysis. Dictionary techniques. Interactive retrieval. Question and answering and data base retrieval. Evaluation of retrieval effectiveness.

[**ICS641 Mathematical Symbol Manipulation** Spring. Credit four hours. Prerequisites: ICS410 and some knowledge of discrete mathematics (e.g., ICS280, ICS481, or Mathematics 431). Not offered 1975–76.]

ICS681 Theory of Algorithms and Computing I Fall. Credit four hours. Three lectures. Prerequisite: ICS482 or consent of instructor.
An advanced treatment of topics related to ICS482, including computational models for random access machines, measures of complexity, analysis of algorithms, arithmetic complexity, lower bounds on complexity of practical problems, reducibilities, and polynomial complete problems. Algorithms discussed include fast Fourier transform, integer and polynomial arithmetic, evaluation, and interpolation.

ICS682 Theory of Algorithms and Computing II Spring. Credit four hours. Three lectures. Prerequisite: ICS481 or consent of instructor.
An advanced treatment of topics related to ICS481, such as axiomatic treatment of computability and computational complexity, including proofs from the axioms of certain theorems such as Rice's theorem, the speed-up theorems, and hierarchy theorems. Also an abstract account of formal languages (AFL's, principal AFL's and others) and algorithmic languages (program schemata, subrecursive languages, and others). At the instructor's discretion, the course will include such topics as structure of the polynomial degrees, universal schemata classes, Grzegorczyk hierarchy, equivalents of the LBA problem, classes of intractable problems, correctness of recursion rules, assignment of meaning to programs, natural unsolvable problems (word problems, Hilbert's 10th Problem, equivalence of schemata, and others), investigations of time-space trade-off (Savitch languages, Cook's class, and others).

ICS709 Computer Science Graduate Seminar Fall and spring. Credit one hour. One seminar. For graduate students interested in computer science. Staff, visitors, and students.
A weekly meeting for the discussion and study of important topics in the field.

ICS712 Theoretical Aspects of Compiler Construction Spring. Credit four hours. Two lectures. Prerequisites: ICS612 and ICS481.
Formal methods of syntactic analysis including precedence, bounded context, and LR techniques. General parsing methods and their time-space complexity. Noncanonical parsing techniques. Formal methods of object code optimization.

ICS719 Seminar in Programming Either term. Credit four hours. One seminar. Prerequisite: ICS611 or consent of instructor.

ICS721 Solutions of Nonlinear Equations and Nonlinear Optimization Problems Fall. Credit four hours. Prerequisite: ICS622 or consent of instructor.
Emphasis on the rigorous analysis of practical numerical algorithms for nonlinear problems. Sample topics are nonlinear functional analysis, constrained and unconstrained minimization, and computationally convenient modifications of Newton's method, including quasi-Newton and penalty function methods and nonlinear least squares.

[**ICS723 Numerical Solution of Ordinary Differential Equations and Integral Equations** Fall. Credit four hours. Prerequisite: ICS622 or consent of instructor. Not offered 1975–76.]

ICS725 Numerical Solution of Partial Differential Equations Spring. Credit four hours. Hours to be arranged. Prerequisite: ICS622 or consent of instructor.
General classification, solution by method of characteristics, finite-difference methods for hyperbolic and elliptic equations, parabolic equations in two dimensions, direct solution of elliptic finite-difference equations, iterative methods for the solution of elliptic equations, block methods for large systems, singularities in elliptic equations, stability in relation to initial value problems, and nonlinear discretization algorithms.

[**ICS727 Introduction to Approximation Theory** Spring. Credit four hours. Prerequisite: ICS622 or consent of instructor. Not offered 1975–76.]

ICS729 Seminar in Numerical Analysis Either term. Credit four hours. Prerequisite: consent of instructor.

ICS733 Selected Topics in Information Processing (Same as Operations Research IOR789.)

ICS734 Seminar in File Processing Fall. Credit and hours to be arranged. Prerequisite: ICS733.

ICS739 Seminar in Information Organization and Retrieval Either term. Credit four hours. Prerequisite: ICS635.

ICS781 Advanced Theory of Computing Spring, alternate years. Credit four hours. Three lectures. Prerequisite: ICS682 or consent of instructor.

At the instructor's discretion, advanced results in automata theory, computability, and computational complexity. Topics may include: noneffectiveness of speed up; honest naming theorem for complexity classes; definition of operator complexity and reducibility classes; comparison of the power of programming languages; relationship between algorithmic languages and formal theories; equivalence algorithms for multitape finite automata; the computational complexity of decision problems (Presburger, Tarski's algorithms, etc.); equivalents of the LBA problem (pebble automata, auxiliary pushdown automata).

[**ICS782 Advanced Topics in Algorithms** Spring, alternate years. Credit four hours. Three lectures. Prerequisite: ICS682 or consent of instructor. Not offered 1975–76.]

ICS789 Seminar in Automata Theory Either term. Credit four hours. One seminar. Prerequisite: consent of instructor.

ICS790 Special Investigations in Computer Science Either term. Prerequisite: consent of a computer science adviser.
Independent research.

ICS890 Special Investigations in Computer Science Either term. Prerequisite: consent of a computer science adviser.
Master's degree research.

ICS990 Speical Investigations in Computer Science Either term. Prerequisite: consent of a computer science adviser.
Doctoral research.

Electrical Engineering

The courses in electrical engineering are listed under the following headings: *Required Courses* (Systems Sequence, Electrophysics Sequence, Laboratory Sequence); *Elective and Graduate Courses* (Theory of Systems and Networks; Electronics; Power Systems and Machinery; Communications, Information, and Decision Theory; Computing Systems and Control; Radio and Plasma Physics and Electromagnetic Theory; General); and *Courses of Interest to Students in Other Curricula.*

Required Courses

Systems Sequence

IEE311 Analysis of Electrical Systems I Fall. Credit four hours. Three lectures, one recitation-computing session. Prerequisites: IEE210 and Mathematics 294 or equivalents.
Kirchhoff laws and network equations, topological methods in circuit analysis. Concept of state; state analysis of linear systems. Transient and steady-state response of networks to exponential excitations, impedance, and transfer functions. Properties of passive and active networks, introductory frequency domain circuit design and synthesis.

IEE312 Analysis of Electrical Systems II Spring. Credit four hours. Three lectures, one recitation-computing session. Prerequisite: IEE311.
Fourier series (response of linear systems to periodic excitation), Fourier integral (response of zero state linear systems to aperiodic excitation), the convolution integral (time domain response of linear systems), application to modulation methods, the single- and double-sided Laplace transform (complete response of linear systems). Time and frequency-domain relations.

IEE401 Random Signals in Systems Fall. Credit four hours. Three lectures, one recitation-computing session. Prerequisite: IEE312 or equivalent.
Description of random signals and analysis of randomly excited systems. An introduction to the concepts of probability, random variables, expectation, random processes, and power spectra. Applications are drawn from the areas of communication, control, and pattern classification.

Electrophysics Sequence

IEE313-314 Electromagnetic Fields and Waves Fall and spring. Credit four hours. Three lectures, one recitation-computing session. Prerequisites: Physics 233 and 234 and Mathematics 294, or equivalent.
Foundations of electromagnetic theory for static and dynamic fields, with applications to energy storage, propagation, and radiation. Topics will include Maxwell's equations, solution of electrostatic problems by separation of variables, Poynting's theorem; plane waves in isotropic dielectrics and conductors, energy in dispersive media, reflection and refraction of plane waves; transmission lines, waveguides, cavities; plane waves in anisotropic dielectrics; radiation and antennas. At the level of *Fields and Waves in Communication Electronics* by Ramo, Whinnery, and Van Duzer.

IEE411 Quantum Theory and Applications Fall. Credit four hours. Three lectures, one recitation-computing session. Prerequisites: IEE313–314 or equivalent.
Introductory quantum mechanics with particular emphasis on those concepts and results necessary for understanding modern solid state and quantum electronic devices. The mechanics of the theory will be

presented in terms of wave functions, operators, and solutions of Schroedinger's equation. Topics will include, for example, wave-particle duality, angular momentum, spin, particles in potential wells, and the hydrogen atom. Where possible, one-dimensional models will be used, but special features of two- and three-dimensional models will be discussed. Applications will include: tunneling, electrons in periodic potential, density of states and energy bands in solids, periodic table, and atomic structure. At the level of *Basic Quantum Mechanics* by White.

Laboratory Sequence

IEE315 Electrical Laboratory I Fall. Credit four hours. Two lectures, two laboratories. Prerequisite: IEE210.
Basic electrical and electronic instrumentation and measurements involving circuits and fields of both active and passive elements; an experimental introduction to solid-state and high-vacuum devices; d.c. machines.

IEE316 Electrical Laboratory II Spring. Credit four hours. Two lectures, two laboratories. Prerequisites: IEE311 and IEE313.
Laboratory studies of solid-state phenomena and devices; experiments illustrating the use of the digital computer in electrical engineering; laboratory studies of high-frequency phenomena and devices; an introduction to a.c. machinery.

Elective and Graduate Courses

Of the following elective and graduate courses, certain ones may not be offered every year if the demand is considered to be insufficient.

Theory of Systems and Networks

IEE620 Bioelectric Systems Spring. Credit three hours (additional one-hour laboratory by special arrangement with the instructors). Three lectures. Prerequisite: IEE312 or Biological Sciences 423 or 427 or Physics 360. R. R. Capranica, M. Kim.
Application of electrical systems techniques to biological problems. Electrical activity of nerve cells; generation and propagation of nerve impulse; voltage clamp technique, Hodgkin-Huxley model, and its phase-plane analysis; electrical excitability and transfer function of neuromuscular systems; synaptic transmission; models of nerve cells and control system analysis of oscillatory activity. Functional neuroanatomy; sensory receptors and encoding in the peripheral and central nervous system; analysis of electrophysiological data; electrodes and instrumentation techniques for monitoring physiological events.

IIE621 Introduction to Biomechanics, Bioengineering, Bionics, and Robots (Same as Theoretical and Applied Mechanics IAH601.) Fall. Credit three hours. Prerequisites: elementary differential equations, linear algebra, and probability; or consent of instructor. H. D. Block.
For course description, see Theoretical and Applied Mechanics IAH601.

IEE623 Active and Digital Network Design Fall. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: IEE312.
Introduction to network synthesis in terms of immittance and scattering parameters. Design of passive filters and matching networks. Active RC filter synthesis using negative-impedance converters (NIC), gyrators, and controlled sources. State-variable synthesis techniques using operational amplifiers. Practical realizations of active RC filters and sensitivity considerations. Active 2-port network theory and design of transistor amplifiers (bipolar and FET). Negative-resistance amplifiers using tunnel diodes and varactors. Introduction to digital signal processing and discrete-time network design. Z-transform and the discrete Fourier transform (DFT). Design of nonrecursive and recursive digital filters. Realizations of digital processing algorithms by either software procedures or hardware implementation. The fast Fourier transform (FFT) algorithms. Topics for the optional laboratory session: design and construction of passive and active filters based on analytical and computer-aided techniques using available computer programs; transistor (bipolar and FET) amplifier design using measured scattering parameters; simulation and hardware implementation of digital filters; computational realizations of DFT and FFT algorithms.

IEE624 Computer Methods in Electrical Engineering Spring. Credit four hours. Prerequisite: IEE312. Open to qualified juniors with consent of instructor. C. Pottle.
Designed to present modern techniques for solving electrical engineering problems on the digital computer. Emphasizes efficiency (minimizing operation counts) and numerical stability rather than theoretical implications. Laboratory session used for experimenting with algorithms in an interactive environment. Solution of linear and nonlinear algebraic equations; root finding; interpolation and extrapolation; integration; solution of ordinary differential equations; random number generators. Parameter optimization. Computer hardware and software considerations in implementing algorithms. Applications to power systems, control systems, circuit design, semi-conductor devices, communication systems.

IEE625 Computer Aided Network Design Fall. Credit four hours. Three lectures. Prerequisite: IEE312. G. Szentirmai.
Frequency and time domain analysis of large linear circuits. State-variable and matrix techniques. D.C. and transient analysis of nonlinear circuits. Tolerancing and sensitivity calculations, adjoint network approach. General formulation of computerized design methods in time or frequency domains. Unconstrained and constrained optimization methods and computer programs. Modeling of circuits. Filter and active RC circuit synthesis methods. Methods of eliminating numerical sensitivity problems. Implementation of algorithms for cascading active and digital circuits.

IEE627 Fundamentals of Linear Networks Fall. Credit four hours. Three lectures. Prerequisite: IEE312. H. Carlin.
Scattering, immittance, hybrid, and state-space for-

malisms. Nonreciprocal and active network properties. Applications of Tellegen's theorem. Passive and active network invariants. Gain and stability theorems. Realizability and energy theorems for multiport networks. Properties of network functions in frequency domain. At the level of *Network Theory: An Introduction to Reciprocal and Non-Reciprocal Circuits* by Carlin and Giordano.

IEE628 Network Theory and Applications
Spring. Credit four hours. Three lectures. Prerequisite: IEE627 or IEE723, or IEE625, or consent of instructor. H. Carlin.
Applications of realizability theory and synthesis to insertion loss design of lumped filters and equalizers, design of distributed RC networks, transmission line filters, and linear phase structures. Amplitude-phase transform methods. Youla's gain bandwidth theory as employed for broadband matching and wideband amplifiers. Modeling and synthesis of distributed systems. Application of transmission line network methods for realization of digital filters.

IEE721 Theory of Linear Systems Fall. Credit four hours. Prerequisites: IEE401 or consent of instructor. C. Pottle.
The state-space model for linear systems. Properties of ordinary linear differential equations. Fundamental and transition matrices. Matrix exponential functions, the Cayley-Hamilton theorem, and the Jordan form. Time invariant and time-varying network and system response. Controllability, observability, stability. Realizability of linear causal systems and applications of Fourier, Laplace, Hilbert Transforms. Paley-Wiener theorem. Distributed systems. At the level of *System Theory* by Padulo and Arbib.

IEE722 Theory of Nonlinear Systems Spring. Credit four hours. Three lectures, Prerequisite: IEE721 or IEE723 or consent of instructor.
Analysis of first- and second-order nonlinear systems with applications. Phase-plane analysis of autonomous systems; singular points, limit cycles, and equilibrium states; theories of Bendixson, Lienard, and Poincare; relaxation behavior in the phase plane; stability of nonlinear systems; the methods of Lyapunov and Popov; circle criteria. Forced nonlinear systems, harmonics, subharmonics, jump phenomena, and frequency entrainment; periodic systems, Floquet theory, Mathieu-Hill theory, applications to the stability of nonlinear systems and to parametrically excited systems.

Electronics

IEE430 Introduction to Lasers and Optical Electronics Spring. Credit four hours. Two lectures, one lecture-recitation, one laboratory. Prerequisite: IEE314 (or equivalent such as IP355 or IP456) and IEE411 (or equivalent such as Physics 443). G. J. Wolga and R. A. McFarlane.
An introduction to stimulated emission devices such as masers, lasers, and optical devices based on linear and nonlinear responses to coherent fields. Material discussed, based on quantum mechanical results, will employ phenomenological theories and will stress applications to modern devices. Subjects will include: propagation of rays, spherical waves, and gaussian beams; microwave and optical resonators and their field characteristics; interaction of matter and radiation; absorption and amplification; threshold for oscillation, rate equations, and output power; specific laser and maser systems; harmonic generation and optical mixing; modulators; parametric converters; detectors; elements of holography. Laboratory, to illustrate and elaborate on specific lecture material, will include: atom, molecular, and solid state laser oscillators and their characteristics; mode properties of coherent optical fields; harmonic generation; optical mixing; optical communications link. At the level of *Introduction to Optical Electronics* by Yariv and *Introduction to Masers and Lasers* by Seigman.

IEE432 Solid State Physics and Applications Spring. Credit four hours. Three lectures, one recitation. Prerequisite: IEE411 or consent of instructor. L. F. Eastman.
Introduction to solid state physics; applications to electronic devices. Classical concepts of solid state physics, including crystal structure, symmetries, reciprocal lattice, x-ray diffraction. Strains, sound waves, phonons in crystals, Brillouin zone representation of periodic structures, band theory, electrons and holes in metals, insulators and semiconductors, electron transport in semiconductors in high electric fields including interaction with phonons. Dielectric and magnetic properties of materials, superconductivity. Engineering applications of some of these physical effects, to thermoelectric elements, transistors, junction lasers, solar cells, Gunn and avalanche diodes, and various other electron devices. The students will prepare a term paper on some physical effect, engineering application, or electron device. At the level of *Introduction to Solid State Physics* by Kittel, 4th edition.

IEE531-532 Electronic Circuit Design Fall and spring. Credit three hours a term. Two lectures, one laboratory. Prerequisite: IEE316. N. H. Bryant.
Design techniques for circuits used in electronic instrumentation. Circuits will be designed to provide specific functions, then constructed and tested in the laboratory. At the level of *Electronics for Scientists* by Malmstadt *et al*.

IEE631-632 Semiconductor Electronics I and II Fall and spring. Credit four hours a term. Three lectures, one laboratory. Prerequisite: IEE315 or equivalent. P. D. Ankrum.
Band theory of solids; properties of semiconductor materials; the physical theory of p-n junctions, metal semiconductor contacts, and p-n junction devices; fabrication and properties of semiconductor devices such as diodes and rectifiers, light-sensitive and light-emitting devices, field-effect and bipolar transistors, unijunction transistors, p-n-p-n devices (diodes, controlled rectifiers, and switches), integrated circuits, etc.; device equivalent-circuit models; the applications of semiconductor devices as active or passive elements in discrete-component and integrated circuits for use as power supplies, power controls, amplifiers, oscillators and multivibrators, pulse circuits, gates and switches, etc.; transistor noise. At the level of *Semiconductor Electronics* by Ankrum.

IEE633–634 Solid State Microwave Devices and Subsystems I and II Fall and spring. Credit three hours a term. Two lectures, one laboratory. Prerequisites: IEE312 and IEE314 or equivalents. G. C. Dalman.

A theoretical and experimental study of modern solid state microwave devices and subsystems based on the Gunn effect diode, IMPATT diode, TRAPATT diode, tunnel diode, p-n diode, and the transistor. Initially, the basic elements of microwave systems and subsystems such as microwave cavities, filters, oscillators, amplifiers, modulators, and detectors are studied, and then more complex elements such as microwave network analyzers, superheterodyne receivers, spectrum analyzers, noise measuring equipment, time domain reflectometers, and experimental Doppler Radars. Typical uses of solid state devices in these subsystems are discussed and analyzed. In many cases the subsystems themselves are used to characterize the circuit parameters of microwave solid state devices and other subsystems. An opportunity to study and operate a wide variety of modern test equipment such as the H.P. network analyzer, sampling oscilloscopes, near-carrier oscillator noise test sets, spectrum analyzers, and microwave laboratory test bench equipment. Participation in the design and testing of varactor tuned oscillators, low noise oscillators, Doppler Radar speed measuring devices, and other devices and subsystems of interest to the class. At the level of *Microwave Semiconductor Devices and Their Applications* by Watson.

IEE635 Integrated Circuit Technology Spring. Credit three hours or four hours with project. Two lectures, one laboratory. Prerequisite: IEE432 or ITB262 or consent of instructor. J. Frey.

Integrated circuit techniques applicable in the fields of computer hardware, telecommunication systems, and opto-electronics are studied, with emphasis on device technology and the specialized approaches to device, circuit, and system design required by large-scale function integration. Computer logic and memory elements, both MOS and bipolar. Telecommunication applications include linear ICs and hybrid integration of microwave solid state devices, such as Gunn and IMPATT oscillators in transmitters and receivers. Integrated optics and compound semiconductor light-emitting and sensing devices. To illustrate the techniques discussed, each student fabricates planar silicon diodes or transistors in the microelectronics laboratory; project students later work on their own in the laboratory on topics of their choice, such as microwave integrated circuits, integrated gates, and opto-electronic devices. At the level of current papers in *IEEE J. Solid State Circuits* and *IEEE Trans. on Electron Devices*.

IEE636 Circuit Design for Integration Fall. Credit three hours. Two lectures, one seminar-design laboratory. Prerequisite: consent of instructor. J. Frey.

Details of circuit design for integration in silicon monolithic integrated circuits and hybrid microwave integrated circuits will be discussed. The limitations of and the advantages afforded by the physics and technology of the processes involved in the fabrication of these circuits will be developed in relation to circuit design. Techniques for complete vertical integration of complex systems, from design through materials processing to final testing. Topics will include: component-dictated limitations on IC design; specialized functional blocks for linear and digital ICs; special components available to monolithic IC designers (e.g., multiple-collector transistors); feedback in linear IC design; chip layout; thermal considerations. The merging of design techniques for microwave integrated circuits and gigabit data rate digital ICs will also be discussed. The class will undertake a design project. Device physics will be considered at the level of *Physics and Technology of Semiconductor Devices* by Grove; additional reading will be at the level of current papers in the *IEEE Journal of Solid State Circuits and Solid State Electronics*.

IEE731 Quantum Electronics I Fall. Credit four hours. Three lectures, one recitation-computing session. Prerequisites: IEE313, IEE314, and Physics 443 or IEE411. C. L. Tang.

A detailed treatment of the physical principles underlying optical masers, related fields, and applications. Topics will include: a review of quantum mechanics and the quantum theory of angular momentum, the interaction of radiation and matter, the quantum mechanical density matrix and macroscopic material properties, theory of the laser and maser. At the level of *Lasers* by Smith and *Laser Physics* by Sargent *et al.*

IEE732 Quantum Electronics II Spring. Credit four hours. Three lectures, one recitation-computing session. Prerequisite: IEE731 or consent of instructor. R. A. McFarlane.

A continuation of the treatment of the physical principles underlying optical masers and related fields. Topics will include: optical resonators; output power of amplifiers and oscillators; dispersive effects and laser oscillation spectrum; Lamb theory; spectroscopy of atoms, molecules, and ions in crystals as examples of laser media; survey of chemical and dye lasers; noise in optical devices; principles of electro-optic and parametric devices.

IEE733 Opto-Electronic Devices Fall. Credit four hours. Three lectures, one recitation. Prerequisite: IEE411 and IEE432, or equivalent. J. M. Ballantyne.

A variety of opto-electronic devices are considered with the aim of providing a physical understanding of some properties of solids which affect their use in optical devices. Topics include: a review of the macroscopic theory of electromagnetic waves in isotropic, lossy, and anisotropic media; symmetry group theory of crystals; discussion of linear electro-optic devices such as modulators and deflectors; classical and quantum mechanical treatment of the microscopic theory of dielectric constant and absorption in solids due to electronic transitions. The band-theory of photoemission is discussed. Physics of hot and cold carrier transport, including effects of trapping, recombination, and scattering are treated, as is photoconductivity in solids and noise in optical detectors. Principles are illustrated by their application to the performance analysis of actual photoconductive, thermal, and photoemissive detectors. Topics are mainly concerned with semiconductors, but metals and insulators are not excluded. At the level of *Dielectrics and Waves* by von Hippel, *Photoconductivity of Semiconductors* by Bube, *Physical Properties of Crystals* by Nye, *Quantum Electronics* by Yariv, and *Optical Processes in Semiconductors* by Pankove.

IEE734 Theory and Applications of Nonlinear Optics Credit four hours. Three lectures, one recitation. Prerequisite: IEE731 or IEE733 or the equivalent of Physics 572. C. L. Tang.
Recent developments in the theory and applications of nonlinear optics and related electro-optic devices. Topics include: properties and theories on nonlinear optical processes; nonlinear and electro-optic properties of III-IV and II-VI compounds and other optical materials; optical mixing; frequency up-conversion and down-conversion; spontaneous and stimulated processes involving nonlinear interactions of electromagnetic waves, phonons, and molecular vibrations; and electro-optical modulators, optical parametric oscillators, and other nonlinear and electro-optical devices. At the level of *Treatise in Quantum Electronics, Vol. I–Nonlinear Optics* edited by Rabin and Tang, and current literature.

IEE735 Solid State Devices I Fall. Credit four hours. Three lectures. Prerequisite: IEE432 or equivalent. C. A. Lee.
Properties of semiconductor devices with emphasis on low-frequency operation (below 1000 GHz). Devices based on the tunnel effect: tunnel diodes, zener diodes, field emitter cathodes, thin film resistors. Devices based on charge flow across semiconductor-semiconductor contacts: p-n diodes, avalanche diodes, transistors, field effect transistors, unipolar transistors. Devices based on metal-semiconductor contacts: Schottky diode, Schottky triode. Emphasis is placed on determining the factors underlying performance capabilities. Equivalent circuits are developed. The student will either carry out a term laboratory project or prepare a term paper on an appropriate contemporary topic. Presented at the level of *Physics of Semiconductors* by Moll and of current papers published in the *IEEE Transactions on Electron Devices*.

IEE736 Solid State Devices II Spring. Credit four hours. Three lectures. Prerequisite: IEE735 or equivalent. C. A. Lee.
Properties of semiconductor devices with emphasis on high frequency operation (above 1000 GHz). The approaches to the analysis to be studied are: ballistic analysis, electronic-network analysis, space-charge wave and coupled-mode analysis. Devices studied include avalanche microwave diode (Read diode), Gunn oscillators, fast response photo diodes, and other contemporary devices. Determination of the factors that underlie performance capabilities. Equivalent circuits are developed. The student will either carry out a term laboratory project or prepare a term paper on an appropriate contemporary topic. Presented at the level of current papers published in the *IEEE Transactions on Electron Devices*.

IEE737 Physics of Solid State Devices Spring. Credit two or three hours. Two lectures. Prerequisite: IEE736 or consent of instructor.
Phenomena and problems associated with conduction in high electric fields, with emphasis on semiconductors. A review of hot electron phenomena, especially where instabilities arise because of multi-valley band structure or other interaction of charge carriers with the host crystal. Basic theory of electron and hole scattering by phonons and examination of methods of obtaining distribution functions from the Boltzmann equation. Modifications required by complications of band structure.

IEE738 Physics of Solid State Devices Credit two or three hours. Two lectures. Prerequisite: IEE737 or consent of instructor.
Analysis of solid state devices of current interest (avalanche, LSA, Gunn devices, etc.) to give an understanding of some of the limitations involved in the design of such devices. Particular scattering mechanisms and band structure complications as factors in obtaining realistic distribution functions. Emphasis will be on analytical solutions because of the physical insight they afford, but numerical methods will be considered also. The number of devices considered will be limited, but subjects of specific interest to individuals can be considered on a seminar basis.

Power Systems and Machinery

IEE551 Contemporary Electrical Machinery I Fall. Credit three hours. Two lecture-recitations, one laboratory-computing session. Prerequisite: IEE312. R. E. Osborn.
Engineering principles. Real- and reactive-power requirements of core materials with symmetrical and biased magnetizing forces; analysis and characteristic prediction of high-efficiency transformers; magnetic amplifiers, energy transfers among electric circuits, magnetic fields and mechanical systems; control of magnetic field distribution by reluctance and winding distribution; traveling fields from polyphase excitation; elementary idealized commutator-type, asynchronous and synchronous machines.

IEE552 Contemporary Electrical Machinery II Spring. Credit three hours. Two lecture-recitations, one laboratory-computing session. Prerequisite: IEE312. R. E. Osborn.
Engineering principles. Production of air-gap magnetic fields; elementary and idealized rotating machines; steady state and transient characteristics of realistic rotating machines; a-c commutator-type single-phase motors; poly-phase synchronous and single-phase induction machines; recently developed types; Saturistor motor, self-excited a-c generators; miscellaneous rotary devices; Hysteresis motor, selsyns, amplidynes, frequency converters.

IEE651 Electric Energy Systems I Credit four hours. Three lecture-recitations, one computing session. Prerequisites: IEE316 and consent of instructor. S. Linke
The physical and engineering principles underlying steady state operation and control of modern electric power systems, with emphasis on the characteristics of major power-system parameters. Theory of electromechanical energy converters, power transfor-

mers, conventional transmission lines and cables, power networks, and other power-system components; use of the digital computer as a dynamic "laboratory" model of a complex power system for load-flow studies. Laboratory-computing periods will include selected experiments with small electromechanical energy converters. At the level of *Elements of Power System Analysis* (2nd ed.) by Stevenson.

IEE652 Electric Energy Systems II Credit four hours. Three lecture-recitations, one computing session. Prerequisite: IEE651. S. Linke.
Continuation of principles presented in Electric Energy Systems I. Transient behavior of power networks. Theory of unbalanced systems, symmetrical components, protective relaying systems, power-system stability, high-voltage direct-current systems, and economic dispatch; use of the digital computer for fault studies and economic analysis. At the level of *Elements of Power System Analysis* (2nd ed.) by Stevenson.

Communications, Information, and Decision Theory

IEE661 Coding Algorithms Fall. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: for the laboratory, FORTRAN, PL/I, or assembly language programming.
Coding algorithms for compression and storage of information, for correction of errors in digital data processing and transmission, and for synchronization. Design, analysis, and implementation of underlying codes. Linear block codes, convolutional codes, maximum likelihood and sequential decoding, linear sequential machines, cyclic codes, Bose-Chaudhuri codes, burst error protection, threshold decoding variable length source coding. Laboratory consists of demonstrations and projects involving design and computer simulation, modification, and evaluation of coding algorithms covered in lecture. At the level of *Error Correcting Codes* by Peterson and Weldon.

IEE662 Fundamental Information Theory Spring. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: IEE410 or equivalent knowledge of probability. Prerequisite for laboratory only: IEE661 with laboratory. T. Fine.
Fundamental results of information theory and their application to information storage, compression, processing, and transmission. The basis of modern design of digital communication systems. Source coding, properties of entropy, and other information measures. Signal selection and detection aspects of noisy transmission channels. Channel capacity and Shannon's coding theorems. Analysis of sequential decoding. Fidelity criteria and rate-distortion function. Communication over gaussian channels. Laboratory projects investigate through computer simulation the statistical problems involved with information source and channel characterization and approximation (quantization), and evaluate the advantages and limitations of the various coding algorithms introduced in IEE661. At the level of *Information Theory* by Ash.

IEE663 Statistical Aspects of Communication Spring. Credit four hours. Three lectures, one recitation. Prerequisite: IEE410 or equivalent. H. S. McGaughan.
Analysis of analog and digital communication systems in the presence of random signals and noise. System optimization, matched filters, linear smoothing, and prediction of stationary processes. Modulation systems, performance of analog systems in time and frequency multiplex with additive noise; digital modulation systems, PCM systems with additive noise. Design of signals for digital transmission. Receiver optimization, design of decision oriented receivers, error bounds; selected topics in hypothesis testing and parameter estimation applied to receiver design.

IEE664 Decision Making in Pattern Classification Spring. Credit three or four hours (three hours with ten and one-half weeks of lectures; four hours with either ten and one-half weeks of lectures and laboratory or fourteen weeks of lectures). Prerequisite: IEE410 or IEE761 or equivalent course in probability. T. Fine.
Concepts and key results of decision theory will be developed and applied to problems of pattern classification (hypothesis testing). Typical pattern classification problems include classification of hand-written, typed, or printed alphanumeric characters; the transcription of speech; identification of regions in photographs; and medical diagnosis. Formulations of the design of pattern classification systems will be examined under a variety of assumptions concerning prior information about the pattern source and the objectives in constructing such a system. The design philosophies to be discussed include those of minimum expected loss, Neyman-Pearson, and minimax risk and regret. Laboratory projects will require the computer-based design and simulation of a pattern classifier for a real or simulated pattern source.

IEE761–762 Random Processes in Electrical Systems Fall and spring. Credit four hours a term. Three lectures. V. Chan.
The concepts of randomness and uncertainty and their relevance to the design and analysis of electrical systems. An axiomatic characterization of random events. Probability measures, random variables, and random vectors. Distribution functions and densities. Functions of random vectors. Expectation and measures of fluctuation. Moment and probability inequalities. Properties and applications of characteristic functions. Modes of convergence of sequences of random variables: laws of large numbers and central limit theorems. Kolmogorov consistency conditions for random processes. Poisson process and generalizations. Gaussian processes. Covariance stationary processes, correlation functions, spectra; Bochner and Wiener-Khinchin theorems. Continuity, integration, and differentiation of sample functions. Hilbert space approach of optimum filtering and prediction. Spectral representation, orthogonal series representations. Markov chains and processes. Linear and nonlinear transformations of random processes.

[**IEE763 Advanced Topics in information Theory** Fall. Credit four hours. Three lectures. Prerequisites: IEE662 and either IEE761 or Mathematics 571, or consent of instructor. Not offered 1975–76.
An in-depth treatment of an information theory research area. The topic varies from year to year and will be chosen from the following subjects: source encoding (rate distortion theory), convolutional codes and sequential decoding, multiterminal communication networks, ergodic theory and information, and complexity and instrumentability of coding schemes.]

IEE764 Foundations of Inference and Decision Making Spring. Credit three hours. Three lectures. Prerequisite: a course in probability and some statistics, or consent of instructor. T. Fine.
An examination of methods for characterizing uncertainty and chance phenomena and for transforming information into decisions and optimal systems. Discussion of the foundations of inference centers on various approaches to the interpretation and formalization of probability, including the following: axiomatic systems of comparative probability; Kolmogorov system of quantitative probability; relative frequency interpretations; computational complexity, randomness, and probability; classical probability and invariance; logical probability and induction; subjective probability and personal decision making. The discussion of the foundations of decision making will center on utility theory, axiomatic rationality, statistical decision theory, the nature of a good system, and recent work on system design when there is little prior information.

Computing Systems and Control

IEE671–672 Feedback Control Systems Fall and spring. Credit three hours (four hours with laboratory). Prerequisite: IEE312 or consent of instructor.
System performance specifications and indices. Analysis and synthesis of linear feedback control systems by root locus and frequency response methods to meet system specifications. Mathematical models of physical systems. Classical cascade and feedback compensation techniques. State space approach to control systems; controllability, observability, infinite-interval optimal-control problem, parameter optimization, state variable feedback. Nonlinear feedback systems; stability by Nyquist, Lyapunov, and Popov conditions. Circle conditions. Limit cycle behavior by describing function techniques. Phase plane analysis. Sampled-data systems and digital compensation. Laboratory work consists of familiarization with system frequency response measurements, transfer function measurements, and transient response measurements; also, design and compensation of linear positional and speed control systems and analysis of nonlinear systems and sampled-data systems. In sampled-data experimentaion, a PDP-11 minicomputer provides the controller element. In all experimentation the emphasis is on correlation of theoretical and experimental results.

IEE674 Hybrid Computation Spring. Credit four hours. Two lectures, one laboratory. Prerequisites: IEE312 and IEE675 or an equivalent background with consent of instructor. N. M. Vrana.
Theory, design, characteristics, and programming of hybrid computer systems; analog computation; special purpose logic programs; the digital computer in a hybrid environment; theory and laboratory work on iterative procedures, steepest descent programs, and parameter optimization and identification. The laboratory work will be with the PDP-11/TR-48 hybrid computer system.

IEE675 Switching Circuits and Logic Design Fall. Credit three hours, or four hours with laboratory. Three lectures, one laboratory. Prerequisite: IEE210 or equivalent. N. M. Vrana.
Boolean algebra, switching devices, combinational circuits, function minimization and decomposition, synchronous and asynchronous sequential circuits, secondary assignments, circuit equivalence, fault detection and diagnosis. Application of principles to design of counters, shift registers, adders, and digital sequential circuits of all kinds. Topics for the laboratory session: design and construction with TTL integrated circuit chips of combinational and sequential circuits. At the level of *Switching Circuits: Theory and Logic Design* by Torng.

IEE676 Computer Structures Spring. Credit three hours, or four hours with laboratory. Three lectures, one laboratory. Prerequisite: IEE675 or Computer Science ICS314, or consent of instructor. Laboratory work in IEE675 is prerequisite for laboratory work in IEE676. N. M. Vrana.
Architecture and design of digital computing systems, hard-wired and microprogrammed control sequencer design, design of input-output and interrupt systems, memory organization, combinational logic and sequential circuits used in computers. In the optional laboratory session, each laboratory group will design and build an 8-bit general-purpose computer using TTL integrated circuit chips. At the level of *Digital Systems: Hardware Organization and Design* by Hill and Peterson.

IEE677 Computer Architecture and Design I Fall. Credit four hours. Prerequisite: IEE676 or consent of instructor. H. C. Torng.
The computer architecture and design sequence emphasizes the design principles and methodology of computers and computer networks. Topics include: data representation, addressing, operations, implications and impacts of technologies, memory hierarchy, concept of virtual memories, evaluation and modeling of memories, control sequencing, microprogramming, microprocessors, processor organizations, trade-offs in terms of performance and cost.

IEE678 Computer Architecture and Design II Spring. Credit four hours. Prerequisite: IEE677. H. C. Torng.
A continuation of IEE677. Topics include: I/0 processing, evaluation and modeling of processors, interconnection studies in computer system design, parallel processing, multiprogramming and multiprocessing systems, novel computer organizations, teleprocessing and computer networks, performance evaluation of computer systems, reliability studies.

IEE771 Estimation and Control in Discrete Linear Systems Fall. Credit four hours. Three lectures. Prerequisite: IEE410 or consent of instructor.
J. S. Thorp.
Optimal control, filtering and prediction for discrete time linear systems with extensive use of the APL/360 system. Approximation on discrete point sets, curve fitting with various error measures. Modeling of discrete time systems with applications to tracking and estimation problems. Optimal control of discrete time linear systems, the principle of optimality. Optimal filtering and prediction for discrete time linear systems, Kalman filtering. Stochastic optimal control, the separation principle. No knowledge of a programming language is assumed. The APL language will be learned during the term through use of a library of programs written for the course. At the level of *Stochastic Optimal Linear Estimation and Control* by Meditch.

IEE772 Optimal Control and Estimation for Continuous Systems Spring. Credit four hours. Three lectures. Prerequisite: IEE771 or consent of instructor.
J. S. Thorp.
Methods of design problem formulation, computational techniques, and mathematical background are developed for the implementation of continuous optimal control and estimation. Deterministic and stochastic controls as well as unbiased estimators are formulated on both finite and infinite time intervals. Extensive examples are given such as re-entry vehicle flight-control, rocket-booster guidance, aircraft tracking, and human operator simulation. Methods of successive approximation and substitution are presented for minimization with respect to parameters and functions, with and without equality and inequality constraints. Properties of Lyapunov and Riccati equations are discussed. Material is illustrated by the student use of an APL library of computer programs for the automated design of continuous controls and estimators.

[**IEE773 Random Processes in Control Systems** Spring. Credit four hours. Three lectures. Prerequisites: IEE762 and IEE772. Not offered 1975–76.
Prediction and filtering in control systems; Gaussian-Markov sequence, Gaussian-Markov process, prediction problem, generalized Wiener filtering, stochastic optimal and adaptive control problems. Selected topics: Bayes decision rule, min-max policy, maximum likelihood estimate, control of systems with uncertain statistical parameters; stochastic differential equations, optimal nonlinear filtering; stability of control systems with random parameters.]

Radio and Plasma Physics and Electromagnetic Theory

IEE410 Thermal and Statistical Physics for Engineers Spring. Credit three hours. Prerequisite: IEE411 or equivalent. R. Liboff.
Thermodynamic principles. Elementary theory of transport coefficients. Electrical noise. Quantum and classical statistics. Black body radiation. Thermal properties of solids. Elementary descriptions of superfluidity, superconductivity, and the laser.

IEE581 Wave Phenomena in the Atmosphere Fall. Credit three hours. Three lecture-recitations. Prequisites: IEE312 and IEE314.
R. Bolgiano.
An elementary treatment of wave phenomena in the atmosphere of the earth, including gravity waves, planetary waves, acoustic waves, radiowaves, and plasma waves; attention is directed to the role of these phenomena in various atmospheric processes and engineering problems such as weather, diffusive transport, air-sea interaction, radio communication, and remote sensing.

[**IEE582 Radio Engineering** Spring. Credit three hours. Three lecture-recitations. Prerequisites: IEE314 and IEE410. Not offered 1975–76.
Electrical systems for communications, control, detection, and other purposes in which radiowaves play a central role: system functions, including generation, modulation, transmission, reception, and demodulation; guidance, radiation, and propagation of radiowaves, including transmission lines and waveguides, antenna systems, and the effects of atmospheric inhomogeneity; system design problems.]

IEE680 Elementary Plasma Physics and Gas Discharges Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: IEE314 or equivalent. C. B. Wharton.
Coordinated lectures and ten experiments. Review of electromagnetic wave theory and applications. Gas discharges and arcs: positive column, collisions, mobility, diffusion, breakdown, sheaths, DC and RF excitation, transition from glow to arc, Langmuir and conductance probes, reflex discharge, effects of magnetic field. Plasma as a dielectric medium, interaction of electromagnetic waves (e.g., microwaves) with plasma in free space and finite regions. Plasma oscillations, space-charge waves, cyclotron harmonic radiation, effects of plasma temperature. At the level of *Plasma Diagnostics with Microwaves* by Heald and Wharton.

IEE681 Introduction to Plasma Physics (Same as Applied and Engineering Physics IP606.) Fall. Credit three hours. Three lectures. Prerequisites: IEE313 and IEE314 or equivalent. Open to fourth-year students at discretion of instructor.
Plasma state; motion of charged particles in fields; adiabatic invariants, collisions, coulomb scattering; Langevin equation; transport coefficients, ambipolar diffusion, plasma oscillations and waves; hydromagnetic equations; plasma confinement, energy principles, and elementary applications. At the level of *Elementary Plasma Physics* by Longmire.

IEE682 Advanced Plasma Physics (Same as Applied and Engineering Physics IP607.) Spring. Credit three hours. Three lectures. Prerequisite: IEE681.
Boltzmann and Vlasov equations; moments of kinetic equation; Chew-Goldberger-Low theory; waves in hot plasmas; Landau damping. Solution of the Vlasov equation by characteristics; ion acoustic instability; streaming instabilities; Bernstein modes; instabilities due to anisotropies in velocity space; gradients in

magnetic field, temperature, and density. Absolute and convective instabilities; effects of collisions and Fokker-Planck terms; method of dressed test particles; high-frequency conductivity and fluctuations; neoclassical toroidal diffusion; relativistic beams.

IEE683 Electrodynamics Fall. Credit four hours. Three lectures, one recitation. Prerequisites: IEE312 and IEE314, or equivalent.
Foundations of electromagnetic theory. Maxwell's equations, electromagnetic potentials, and integral representations of the electromagnetic field. Special theory of relativity. Radiation of accelerated charges and Cerenkov radiation. Electrodynamics of dispersive and anisotropic media. Normal modes of waveguides and cavities. Surface waves and leaky waves. At the level of *Theory of Electromagnetism* by Jones.

IEE684 Microwave Theory Spring. Credit four hours. Three lectures, one recitation. Prerequisites: IEE312 and IEE314, or equivalent.
Theory of passive microwave devices. Waves in homogeneous and inhomogeneous waveguides; propagation and distortion of pulses; application of gyrotropic media to nonreciprocal waveguide devices. Scattering matrix analysis of multiport junctions, resonant cavities, directional couplers, isolators, circulators. Periodic waveguides. Elastic waves in solids and their microwave applications. At the level of *Introduction to the Theory of Microwave Circuits* by Kurokawa.

IEE685–686 Upper Atmosphere Physics I and II Fall and spring. Credit three hours a term. Three lectures. Prerequisite: IEE314. M. Kelley.
The physical processes governing the behavior of the earth's ionosphere and magnetosphere. Topics include diagnostic measurement techniques; production, loss, and transport of charged particles in the ionosphere and magnetosphere; temperature variations; airglow; tidal motions, winds, and gravity waves in the ionosphere; the electrical conductivity of the ionosphere, the dynamo-current system, and the equatorial and auroral electrojets; plasma instabilities in the ionosphere; the solar corona; the generation and properties of the solar wind and interplanetary magnetic field; interaction of the solar wind with the earth's magnetosphere and ionosphere; acceleration and drift of energetic particles in the magnetosphere; precipitation of particles and the aurora; magnetic and ionospheric storms. At the level of *Introduction to Ionospheric Physics* by Rishbeth and Garriott.

[**IEE687 Radiowave Propagation I** Fall. Credit three hours. Three lectures. Prerequisites: IEE314 and IEE410 or equivalent. Not offered 1975–76.
Propagation in the earth's environment: troposphere, ionosphere, magnetosphere, and interplanetary space. Diffraction and surface wave propagation; tropospheric refraction and ducting; propagation in the ionospheric plasma, including magnetoionic theory, cross modulation and Faraday rotation, whistler mode propagation, ion effects and ion whistlers, group velocity and ray tracing; radar astronomy; WKB solutions of the coupled-wave equations.]

[**IEE688 Radiowave Propagation II** Spring. Credit three hours. Three lectures. Prerequisite: IEE687 or equivalent. Not offered 1975–76.
Full-wave solutions of the coupled-wave equations, interactions between particles and waves in the magnetosphere, the scattering of radio waves from random fluctuations in refractive index, tropospheric and D region ionospheric scatter propagation, incoherent scatter from the ionosphere and its use as a diagnostic tool, radio star and satellite scintillations and their use in studying the ionosphere and solar wind.]

IEE781 Kinetic Theory (Same as Applied and Engineering Physics IP761.) Fall, alternate years. Credit three hours. Two lectures. Prerequisite: Physics 561, 562, or consent of instructor. R. L. Liboff.
Designed for students who want a firm foundation in fluid dynamics, plasma-kinetic theory, and nonequilibrium statistical mechanics. Brief review of classic dynamics. The concept of the ensemble and the theory of the Liouville equation. Prigogine and Bogoliubov analysis of the BBKGY sequence. Master equation, density matrix, Wigner distribution. Derivation of fluid dynamics. Transport coefficients. Boltzmann, Krook, Fokker-Planck, Landau, and Balescu-Lenard equations. Properties and theory of the linear Boltzmann collision operator. Chapman-Enskog and Grad methods of solution of the Boltzmann equation. Klimontovich formulation. Coarse graining and ergodic theory. At the level of *Introduction to the Theory of Kinetic Equations* by Liboff.

IEE782 Nonlinear Phenomena in Plasma Physics Fall. Credit three hours. Corequisite: IEE682. E. Ott.
Nonlinear processes in plasmas and their implications for such diverse fields as controlled thermonuclear fusion and space plasmas. (1) Coherent nonlinear processes (echoes, trapped particles, solitary waves, shocks, and parametric instabilities); (2) statistical theories of plasma turbulence (quasilinear theory, wave kinetic equations, the random phase approximation, resonant mode-mode coupling, nonlinear Landau damping, Dupree's theory of strong plasma turbulence, anomalous resistivity and diffusion, and turbulent heating). At the level of current articles in *Physics of Fluids* and *Journal of Experimental and Theoretical Physics (Soviet Physics).*

General

IEE591–592 Project Fall and spring. Credit three hours.
Individual study, analysis, and, usually, experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing his project; an engineering report on the project is required.

IEE691–692 Special Topics in Electrical Engineering Credit one to three hours.
Seminar, reading course, or other special arrangement agreed upon between the students and faculty members concerned.

IEE791–792 Electrical Engineering Colloquium Fall and spring. Credit one hour a term. For graduate students enrolled in the Field of Electrical Engineering.
Lectures by visiting authorities, staff, and graduate students. A weekly meeting for the presentation and discussion of important current topics in the field.

IEE793–794 Electrical Engineering Design Fall and spring. Credit three hours per term. Offered for students enrolled in the M. Eng. (Electrical) degree program.
Utilizes real engineering situations to present fundamentals of engineering design.

IEE795–799 Special Topics in Electrical Engineering Credit one to three hours.
Seminar, reading course, or other special arrangement agreed upon between the students and faculty members concerned.

Courses of Interest to Students in Other Curricula

IEE210 Introduction to Electrical Systems Either term. Credit three hours. Three lecture-recitations. Prerequisites: Mathematics 192 and Physics 112.
A core-science course. See description under Division of Basic Studies.

IEE220 Electrical Engineering Laboratory Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: IEE210.
An experimental introduction to basic electrical measuring techniques and instruments, electronic devices, and circuits. Design of practical analog and digital circuits. Use of integrated circuits. Individual projects.

Engineering Physics

See p. 71.

Environmental Engineering

See p. 78.

Geological Sciences

The courses in geological sciences are listed under the following headings: *Freshman and Sophomore Courses; Junior, Senior, and Graduate Courses;* and *Field Courses.*

Freshman and Sophomore Courses

IGE101 Introductory Geological Sciences Either term. Credit three hours. Two lectures, one laboratory; evening examinations. W. B. Travers (fall), J. M. Bird (spring).
Earth processes, features, and history. Basic knowledge for more specialized courses or a major in geological sciences. Materials, structure, and internal condition of the earth, and the physical and chemical processes at work. Earth history, evolution of continents, oceans, mountain systems, and other features; development of animals and plants.

IGE102 Introduction to Historical Geology Spring. Credit three hours. Two lectures, one laboratory; evening examinations. Prerequisite: IGE101 or consent of instructor. J. L. Cisne and staff.
A continuation of IGE101. History of the earth and life in terms of evolutionary processes. The geologic record, its formation, and interpretation of earth history. Introduction to the evolution of life, to fossils and their use in reconstructing past environments and dating rocks.

IGE103 Earth Science Fall. Credit three hours. (See Earth Science Laboratory IGE105.) Three lectures. A. L. Bloom.
Physical geography, including the spatial relationships of the earth, moon, and sun that determine the figure of the earth, time, seasons, atmospheric and oceanic circulation, and climates.

IGE105 Earth Science Laboratory Fall. Credit one hour. To be taken concurrently with IGE103. One laboratory. A. L. Bloom
Observation and calculation of daily, monthly, and seasonal celestial events; topographical mapping and map interpretation; world climatic regions.

IGE131 Geology and the Environment Fall. Credit three hours. Two lectures, one laboratory, field trips. G. A. Kiersch.
The principles of geological science, with emphasis on the physical phenomena and rock properties as they influence the natural environments of man.

IGE162 Mineral and Energy Resources Spring. Credit three hours. Two lectures. B. Bonnichsen, W. B. Travers.
The nature, occurrence, distribution, and availability at home and abroad of mineral resources, including political and economic aspects. The energy crises and the long-term development of additional energy reserves; exploration and recovery methods and the environmental damage from recovery.

IGE232 Environmental Geology Spring. Credit three hours. Prerequisites: IGE101–102, or IGE131. Two lectures, one laboratory; field trips. G. A. Kiersch.
The geologic basis of man's environment and relevant impact on such aspects as: ecosystems, trace elements/health, energy/mineral resources, land use, population, laws and policies, pollution, disposal of radioactive/industrial wastes, and geological hazards. Laboratory, discussions, field trips, and a special project.

Junior, Senior, and Graduate Courses

Of the following, the core courses IGE325, IGE345, IGE355–356, IGE376, and IGE388 may be taken by those who have successfully completed IGE101–102 or the equivalent, or who can demonstrate to the instructor that they have adequate preparation in mathematics, physics, chemistry, biology, or engineering.

IGE325 Structural Geology and Sedimentation Spring. Credit four hours. Three lectures, one laboratory. Prerequisite: IGE101 or consent of instructor. W. B. Travers.
Nature, origin, and recognition of geologic structures. Behavior of geologic materials. Geomechanical and tectonic principles applied to the solution of geologic problems. Introduction to the sedimentary and hydraulic processes and petrology of sedimentary rocks. Description, classification, provenance, transportation, diagenesis, and depositional environment of sediments.

IGE344 Geological Oceanography Spring. Credit three hours. Three lectures. Training cruise, depending on ship availability. Prerequisite: IGE102 or Biological Sciences 461. A. L. Bloom, D. E. Karig.
Shoreline erosion, transportation, and deposition; origin and structure of continental shelves and ocean basins. Geologic processes and geomorphic development in the marine environment.

IGE345 Geomorphology Fall. Credit four hours. Two lectures, one laboratory; additional assigned problems. Prerequisite: IGE102 or consent of instructor. A. L. Bloom.
Description and interpretation of land forms in terms of structure, process, and stage.

IGE355 Mineralogy, Petrology, and Geochemistry I Fall. Credit four hours. Two lectures, one laboratory; assigned problems and readings; field trips. Prerequisite: IGE102 or consent of instructor. B. Bonnichsen.
Megascopic and optical properties, chemistry, and petrogenetic significance of rock-forming minerals. Principles of phase equilibria as applied to igneous and metamorphic systems. Description, classification, chemistry, petrography, origin, and regional distribution of igneous and metamorphic rocks. Geochemical distribution of trace elements and isotopes in igneous and metamorphic systems.

IGE356 Mineralogy, Petrology, and Geochemistry II Spring. Credit four hours. Two lectures, one laboratory; assigned problems and readings; field trips. B. Bonnichson.
A continuation of IGE355.

IGE376 Historical Geology and Stratigraphy Fall. Credit four hours. Two lectures, two laboratories; additional assigned problems. J. L. Cisne.
Application of geologic principles to interpretation of earth history; development of the geologic column, geochronology, and geochronometry; correlation and the zone concept; sedimentary environments and provinces; geosynclines and platforms; problems of the pre-Cambrian and continental evolution.

IGE388 Geophysics and Geotectonics Spring. Credit four hours. Three lectures, one laboratory. Prerequisites: Mathematics 112 and Physics 208 or equivalent. B. L. Isacks, J. E. Oliver.
Global tectonics and the deep structure of the solid earth as revealed by investigations of earthquakes, earthquake waves, the earth's gravitational and magnetic fields, and heat flow.

IGE410 Experiments and Techniques in Earth Sciences Spring. Credit two hours. Prerequisites: Physics 207–208 and Mathematics 191–192 or equivalents, or consent of instructor. S. Kaufman.
Laboratory and field experiments chosen in accordance with students' interests and designed to familiarize them with instruments and techniques used in earth sciences. Independent work is stressed.

IGE423 Petroleum Geology Fall. Credit three hours. Three lectures, one laboratory; field trip. Recommended prerequisite: IGE325. W. B. Travers.
Sedimentation and tectonics as conditions of hydrocarbon entrapment. Problems of petroleum exploration, including geophysical investigations, subsurface mapping, the movement of underground fluids, and the geophysical properties of subsurface fluids and sediments. The organization and operation of the petroleum industry; on-shore and off-shore exploration and production techniques.

IGE424 Tectonics of Orogenic Zones: Modern and Ancient Spring. Credit three hours. One lecture. Prerequisite: consent of instructors. D. E. Karig, W. B. Travers.
A comparative study of island arcs and mountain ranges.

IGE428 Geomechanics Spring. Credit three hours. Three lectures. Prerequisites: Mathematics 240 or 296; IGE101. D. E. Karig, D. L. Turcotte.
Use of mathematical analysis to explain such geological observations as ocean ridges — their thermal structure, elevation, heat flow, and gravity; ocean trenches — the structure and mechanics of the bending lithosphere; folding — buckling, viscous and plastic flow; faulting — a detailed mechanical and geological study of the San Andreas fault; intrusives — geothermal power.

IGE436 Rock Deformation Spring. Credit three hours. Three lectures. Prerequisite: IGE325. G. A. Kiersch.
Review of stress analysis and behavior of materials, both the rock mass and sample. Fundamentals of deformation pertaining to the crustal rocks and the problems of geological sciences.

IGE461 Mineral Deposits: Metals Fall. Credit four hours. Two lectures, one laboratory; assigned problems and readings; field trip. Prerequisite: IGE356 or consent of instructor. B. Bonnichsen.
Description, origin, distribution, and economic signifi-

cance of the principal types of metallic ore deposits; principles and processes involved in their formation. Magascopic and microscopic identification of principal opaque ore minerals; handsample and microscopic study of representative ore and rock suites.

[**IGE462 Mineral Deposits: Nonmetals** Spring. Credit four hours. Three lectures, one laboratory; field trips. Prerequisite: IGE461 or consent of instructor. Staff. Not offered 1975–76.]

IGE471 Invertebrate Paleontology Fall. Credit four hours. Two lectures, two laboratories. Prerequisite: IGE102; invertebrate zoology recommended. J. L. Cisne.
Paleobiology and classification of important fossil invertebrates. Problems of evolution. Use of organisms in reconstructing past environments.

IGE483 Marine Tectonics Fall. Credit three hours. Two lectures; possible field trips. Prerequisites: IGE325 and a course in physics or geophysics. D. E. Karig.
Study of geophysical and geological characteristics of the earth's crust beneath the oceans. Review of strengths and limitations of marine exploratory techniques. Emphasis on recent geologic data concerning plate margins in the ocean, especially the island arc systems.

IGE485 Physics of the Earth I Fall. Credit three hours. Two lectures, one laboratory. Open to upperclass engineers, majors in the physical sciences, and others by consent of instructor. D. L. Turcotte.
Rotation and figure of the earth, gravitational field, seismology, geomagnetism, creep and anelasticity, radioactivity, earth's internal heat, continental drift, and mantle convection.

[**IGE486 Physics of the Earth II** Fall. Credit three hours. Open to upperclass engineers, majors in the physical sciences, and others by permission of instructor. IGE485 not required prerequisite. Not offered 1975–76.]

IGE488 Introduction to Geophysical Prospecting Fall. Credit three hours. Two lectures. Prerequisites: Physics 112–218 and Mathematics 191–192, or equivalents, or consent of instructor. S. Kaufman.
Physical principles, instrumentation, operational procedures, and interpretation techniques in geophysical exploration for oil, gas, and minerals. Seismic reflection, seismic refraction, gravity, and magnetics methods of exploration.

IGE490 Senior Thesis Either term. Credit one hour. Staff.

IGE632 Exploration Geology Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: field geology and, usually, graduate standing. G. A. Kiersch.
Methods of exploration and appraisal of geologic data from both field and laboratory investigations. Assessment of environmental geology and the presentation of direct and indirect information for professional purposes.

IGE633 Environmental/Engineering Geology: Theory Fall. Credit three hours. Two lectures, one laboratory; field trips. Prerequisite: IGE325; IGE355–356 and IGE345 recommended. G. A. Kiersch.
Physical phenomena and rock properties important to engineering and environmental planning, development, and operation. Underground fluids, subsidence, gravity movement, seismicity, geomechanics and stresses, rock mechanics, weathering, and geologic materials of construction. Geologic problems encountered in practice; influence of natural and man-made environmental factors.

[**IGE635 Engineering Geology: Practice** Fall, alternate years. Credit three hours. Two lectures, one laboratory; field trips. Prerequisites: IGE633 or IGE325, IGE355–356, and IGE345. Not offered 1975–76.
Geological principles applied to the planning, design, construction, and operation of engineering works. Case histories, analysis and evaluation of physical environmental factors, remedial treatment, and reports.]

IGE642 Glacial and Quaternary Geology Spring. Credit three hours. Two lectures, one laboratory; several Saturday field trips. Prerequisite: IGE345 or consent of instructor. A. L. Bloom.
Glacial processes and deposits and the stratigraphy of the Quaternary.

IGE673 Stratigraphy Fall. Credit three hours. Two lectures, one additional hour to be arranged. Prerequisite: IGE376. J. M. Bird.
Principles of stratigraphy, developed by detailed study of selected American and European systemic examples.

IGE681 Geotectonics Fall. Credit four hours. Two lectures. Prerequisite: consent of instructor. J. M. Bird.
Theories of orogeny; ocean and continent evolution. Kinematics of lithosphere plates. Rock-time assemblages of modern oceans and continental margins, and analogs in ancient orogenic belts. Time-space reconstructions of specific regions. Problems of dynamic mechanisms—corollaries and evidence from crustal features.

IGE687 Seismology Fall. Credit three hours. Two lectures, one additional hour to be arranged. Prerequisite: Mathematics 421–422–423 or equivalent. B. L. Isacks, J. E. Oliver.
Theories of generation and propagation of elastic waves in the earth. Derivation of the structure of the earth and the mechanisms of earthquakes from seismological observations.

IGE688 Gravity, Geomagnetism, and Heat Flow Spring. Credit three hours. Two lectures, one additional hour to be arranged. Prerequisite: Mathematics 421–422–423 or equivalent. D. L. Turcotte.
Measurement and mathematical description of the gravitational and magnetic fields of the earth; heat flow; gravitational, magnetic, and heat flow anomalies and the structure of the earth; theories of the origin of the geomagnetic field. Selected advanced topics.

IGE690 Seminars and Special Work Throughout the year. Credit two hours a term. Prerequisite: consent of instructor.
Advanced work on original investigations in geological sciences.

IGE690–1 Structural geology, sedimentation, and tectonics. W. B. Travers.

IGE690–2 Petrology of ingeneous rocks and metallic ore deposits. B. Bonnichsen.

IGE690–3 Coastal geomorphology and Pleistocene geology. A. L. Bloom.

IGE690–4 Environmental-engineering geology, geomechanics, and hydrogeology. G. A. Kiersch.

IGE690–5 Geophysics, seismology, gravity, magnetism, heat flow, geotectonics. B. L. Isacks, D. E. Karig, S. Kaufman, J. E. Oliver, D. L. Turcotte.

IGE690–6 Invertebrate paleontology and paleoecology. J. L. Cisne.

IGE690–7 Mineral deposits and resources. Staff.

IGE690–8 Environmental problems. W. B. Travers.

IGE690–9 Marine geology. D. E. Karig.

IGE690–10 Plate tectonics and geology. J. M. Bird.

Field Courses

[**IGE601 Intersession Field Trip** Credit one hour. Prerequisites: IGE101–102 or equivalent and consent of instructor. Not offered 1975–76.
A trip of one week to ten days in an area of interesting geology in the lower latitudes. Travel and subsistence expenses to be determined. Interested students should contact the instructor during the early part of the fall semester.]

IGE602 Introductory Field Geology Spring. Credit one hour. Four weekend trips and two laboratories; times to be arranged. Prerequisites: one introductory course in geology and IGE325, or consent of instructor. W. B. Travers.
Techniques of field mapping, using selective localities in southern New York and vicinity. Use of Brunton compass, field descriptions of rock types, identification and field use of fossils, and description of land forms. Construction of detailed and regional geologic maps, cross sections and columnar sections. Emplacement of rocks and their subsequent geologic history.

IGE704 Western Field Course Spring. Credit six hours. Weekly lecture and a 38-day trip to California, Nevada, and Utah. Prerequisites: four courses in geological sciences at the 300 level, and consent of instructor. W. B. Travers.
A comparative study of California Coast Range, Sierra Nevada, Basin and Range of Nevada, and Uinta Mountains, Utah. Pretrip seminars and extensive reading at Cornell. Study of Mesozoic subduction near San Luis Obispo, California; recent earth movements along the San Andreas fault near San Francisco; granitic pluton emplacement and volcanism in the northern Sierra Nevada; multiplephase mountain building near Dixie Valley, Nevada; sedimentology and block faulting of the Uinta Mountains, Utah. Five-day raft trip on the Green River through the core of the Uinta Mountains. Visit to an oil field in California and a copper mine in Nevada. Lectures and field trips with local experts.

Industrial Engineering and Operations Research

Undergraduate Courses

IOR213 Systems Analysis and Design
Spring. Credit three hours. Two lectures, one recitation. Prerequisite: Mathematics 293. J. A. Muckstadt.
See course description under Division of Basic Studies.

IOR260 Introductory Engineering Probability Either term. Credit three hours. Three lectures. Prerequisite: first year calculus. D. C. Heath, N. U. Prabhu, M. S. Taqqu, L. I. Weiss.
See course description under Division of Basic Studies.

IOR270 Basic Engineering Statistics Either term. Credit three hours. Two lectures, one recitation. Prerequisite: first-year calculus. H. M. Taylor 3d.
See course description under Division of Basic Studies.

IOR301 Introduction to Systems Engineering
Fall. Credit three hours. Three lecture-recitations. B. W. Saunders.
An introduction to modern systems engineering concepts. Historical development of industrial engineering, the emergence of operations research techniques, and the maturing of classical industrial engineering into the more universal systems engineering methodology. Industrial organizations and their functions of production, marketing, costing, etc.; parallels drawn with their counterparts in health-care systems, governmental systems, and other service industries to demonstrate the universality of systems methodology.

IOR320–321 Optimization Models and Methods in Industrial Engineering and Operations Research I–II Fall: IOR320; four hours credit; three lectures, one recitation. Spring: IOR321; three hours credit; two lectures, one recitation. Prerequisites: Mathematics 293 and the rudiments of computer programming and probability (as presented in IOR260). M. J. Todd.
Formulation, analysis, and solution of classes of optimization models arising in industrial engineering and operations research. Modeling of resource allocation, production planning, distribution, inventory, location, investment, and engineering design problems. Determination of objectives and decision alternatives.

Properties and solution techniques for models described in terms of the following dichotomies: deterministic-probabilistic, univariate-multivariate, constrained-unconstrained, linear-nonlinear, discrete-continuous, static-dynamic, and single-multiple decision makers. Methodologies include the simplex method, gradient techniques, recursive procedures, heuristics, etc. Synthesis of IE/OR techniques; interplay between formulation and solution.

IOR335 Introduction to Game Theory Spring. Credit three hours. Three lectures. L. J. Billera.
A broad survey of the mathematical theory of games, including such topics as two-person matrix and bimatrix games; cooperative and non-cooperative n-person games; games in extensive, normal, and characteristic function form. Economic market games. Structure theory for games arising from complex organizations.

IOR350 Cost Accounting, Analysis, and Control Either term. Credit four hours. Three lecture-recitations, one computing session. R. N. Allen.
Accounting theory and procedures, financial reports; product costing in job-order and process-cost systems — historical and standard costs; cost characteristics and concepts for analysis, control, and decision making; differences between accounting and engineering objectives in the development and uses of cost data. Introduction to decision making based on economic criteria.

IOR361 Probabilistic Models in Industrial Engineering and Operations Research Spring. Credit four hours. Three lectures, one computing session. Prerequisite: IOR260 or equivalent. D. C. Heath.
Various probabilistic techniques are developed and used to model random processes. The emphasis is on deriving and building descriptive probabilistic models of processes found in a variety of practical situations. Topics include: Markov chains, Poisson process with extensions, exponential models, queuing models, renewal processes, and reliability models.

IOR370 Introduction to Statistical Theory with Engineering Applications Either term. Credit four hours. Three lectures, one recitation. Prerequisite: a course in probability (e.g., IOR260). B. W. Turnbull, M. S. Taqqu.
Provides a working knowledge of basic statistics as it is most often applied in engineering work, and a basis in statistical theory for continued study and further application. A variety of statistical procedures are presented, together with the theoretical principles on which they are based. May be followed by IOR512 or IOR471 or by Industrial and Labor Relations 311 or Statistics and Biometry 511. Topics include a review of distributions of special interest in statistics: normal, chi-square, binomial, Poisson, t and F; introduction to statistical decision theory and Bayes procedures; basic principles underlying hypothesis tests: the Neyman-Pearson theory; one- and two-sided hypothesis tests of the mean of a normal distribution when the standard deviation is known (unknown); hypothesis tests concerning the variance of a normal distribution; basic principles of point and confidence interval estimation; minimum variance unbiased estimators, maximum likelihood estimation; confidence-interval estimates of the mean and variance of a normal distribution; the bivariate normal distribution and correlation; linear regression and curve fitting by least squares.

IOR383 Applications of Computer Science in Industrial Engineering and Operations Research Spring. Credit four hours. Two lectures, one computing session. Prerequisites: IOR260, IOR370, and Computer Science ICS211. E. K. Clemons.
The application of computers in the analysis of industrial engineering and operations research problems. Simulation methodology. Design of data processing systems for operational control. Use of statistical and mathematical programming packages.

IOR410 Industrial Systems Analysis Fall. Credit four hours. Three lectures, one computing session. Prerequisites: IOR350 and IOR370, or equivalent. A. Schultz, Jr.
Engineering economic analysis, including fundamentals of engineering economy, cost-benefit analysis, replacement, taxation effects, decision making based on economic considerations. Operations analysis, including process flow, process evaluation, procedural analysis, resource layout, methods analysis and design, work measurement and estimation, job evaluation.

IOR421 Production Planning and Control Spring. Credit four hours. Three lectures. Prerequisites: IOR320 and IOR361 or consent of instructor. W. L. Maxwell.
Methods for the planning and control of large-scale operations, with emphasis on manufacturing systems. Planning and control of inventories; production planning and workforce leveling and smoothing; loading and scheduling of production resources; sequencing and dispatching of jobs; integrated planning and control procedures for single, multiple, and hierarchically structured products. Mathematical, statistical, and computational methods for performing these functions. Implimentation problems and economic interpretations of procedures are covered.

IOR435 Introduction to Game Theory Spring. Credit four hours. Three lectures, one recitation. Prerequisite: IOR320 or IOR622. L. J. Billera.
The same topics as IOR335; lectures will be common for both courses. Registrants in IOR435 will have recitations requiring the indicated prerequisites.

IOR437 Dynamic Programming Fall. Credit four hours. Three lectures, one recitation. Prerequisites: IOR320 or IOR622, and IOR260. L. E. Trotter, Jr.
This course will have lectures in common with IOR637, but will include one extra recitation.

IOR471 Applications of Statistics to Engineering Problems Fall. Credit four hours. Three lectures, one recitation. Prerequisite: IOR370 or equivalent. T. J. Santner.
Applications of regression and correlation techniques to problems arising in engineering and the sciences.

Introduction to design and analysis of experiments. Elementary nonparametric procedures. Single-stage, two-stage, and sequential sampling rules.

Graduate Courses

IOR516 Mathematical Models—Development and Application Fall. Credit four hours. Four recitation-laboratories. Prerequisites: IOR320 and IOR361 or equivalent. J. Zahavi.
A laboratory course concerned with structuring problems and operational systems as analytic or mathematical models. A sequence of situations is considered for which students must specify criteria, identify parameters and interacting elements, specify data, and construct a representative model to describe the situation or accomplish their specified objectives. Models are examined for their usefulness in analysis, synthesis, and design.

IOR551 Advanced Engineering Economic Analysis Spring. Credit four hours. Two lecture-discussions plus occasional individual conferences. Prerequisite: IOR350 or consent of instructor. A. Schultz, Jr.
Brief review of cost accounting, control, and use of cost information for financial reporting and decision making. Capital expenditure planning procedures. Planning, budgeting, and control. Product and market decisions, interdependence of organization, operations, and economic decisions. Cash flow. Measures and control of nonmanufacturing activities. Project management. Related topics of interest to class.

IOR561 Queuing Theory and Its Applications Fall. Credit three hours. Three lectures. Prerequisites: IOR361 and consent of instructor. N. U. Prabhu.
Review of Poisson and birth-death processes and Markov chains. Basic queuing models. Finite source, group arrivals, bulk service, finite capacity, balking, and priorities. Design and control of queuing systems. Statistical inference from queuing processes. Solution techniques (including simulation) for queuing problems. Applications to scheduling and equipment maintenance. Transportation models. Models for highway and urban traffic networks. Models for analysis of computer systems.

IOR562 Inventory Theory Fall. Credit three hours. Three lecture-recitations. Prerequisites: IOR361 and consent of instructor. J. A. Muckstadt.
An introduction to mathematical inventory theory with applications to inventory management, production control, control of pest population, and other problems of business and government. Deterministic and stochastic models are developed using techniques of dynamic programming, stationary analysis, and network flows. Emphasis is placed on classical models and their application.

IOR570 Statistical Methods in Quality and Reliability Control Spring. Credit three hours. Three lectures. Prerequisite: IOR370 or equivalent. B. W. Turnbull.
Control concepts: control methods for attributes and variables; process capability analysis; attributes acceptance sampling plans and procedures; double and multiple sampling plans; elementary procedures for variables; acceptance-rectification procedures; basic reliability concepts; exponential and normal distributions as models for reliability applications; life and reliability analysis of components; analysis of series and parallel systems; stand-by and redundancy; elementary sampling-inspection procedures used for life and reliability.

[**IOR614 Facilities Location and Design** Spring. Credit three hours. Three lecture-recitations. Prerequisite: IOR320 or IOR622 or consent of the instructor. Not offered 1975–76.
Location and facility design models involving various objectives and different feasibility assumptions. Emphasis is on formulation, analysis, and solution techniques using operations research methods. Applications in industrial and environmental engineering, regional planning, and management science.]

IOR622 Operations Research I Fall. Credit three hours. Three lecture-recitations. Prerequisite: consent of instructor. Not open to students who have had IOR320. J. Zahavi.
Model design, methodology of operations research, linear programming, transportation problem, assignment problem, dual theorem, parametric linear programming, integer programming, nonlinear programming, dynamic programming, introduction to inventory theory, game theory, comprehensive problems, and case studies.

IOR623 Operations Research II Spring. Credit three hours. Three lecture-recitations. Prerequisite: IOR260 and IOR270 or consent of instructor. Not open to students who have had IOR361. J. A. Muckstadt.
Models for inventory and production control. Replacement theory; queuing, including standard birth and death process model and nonstandard models; application of queuing theory. Simulation. Illustrative examples and problems.

IOR625 Scheduling Theory Spring. Credit three hours. Three lecture-recitations. Prerequisite: consent of instructor. L. E. Trotter, Jr.
Scheduling problems; problem definition and performance measures. Single resource scheduling. MxN scheduling problems. Priority queuing approaches. Simulation to job shop dispatching and heuristic procedures.

IOR630 Linear Programming Fall. Credit three hours. Three lecture-recitations. Prerequisite: advanced calculus and basic linear algebra, or IOR320-321. L. J. Billera.
Basic theory of polyhedral convex sets including polyhedra, polytopes, polyhedral cones, and the notions of extreme points and rays. Separating hyperplane theorems for polyhedral convex sets. Relationship to systems of linear equations and inequalities, including the Farkas lemma. Dual pairs of linear programming problems and the duality theorem. Simplex method and dual simplex method.

Transportation and assignment problems. Decomposition principle. Introduction to integer and nonlinear programming.

IOR631 Integer Programming Spring. Credit three hours. Three lecture-recitations. Prerequisite: IOR730. L. E. Trotter, Jr.
Discrete optimization. Linear programming problem in which the variables are restricted to be integers. Theory, computation, and applications.

[**IOR632 Nonlinear Programming** Spring. Credit three hours. Three lecture-recitations. Prerequisite: IOR630. Not offered 1975–76.
Necessary and sufficient conditions for unconstrained and constrained optima. Computational methods, including interior (e.g., penalty functions), boundary (e.g., gradient projection), and exterior (e.g., cutting plane) approaches.]

[**IOR633 Combinatorial Analysis** Spring. Credit three hours. Three lecture-recitations. Prerequisite: IOR640 or consent of instructor. Not offered 1975–76.
A seminar in which students study and lecture on selected topics in combinatorics.]

[**IOR634 Graph Theory** Spring. Credit three hours. Three lecture-recitations. Not offered 1975–76.
Finite, infinite, directed, undirected, combinatorial, and topological graphs. Connectedness, planarity and imbedding problems, enumeration problems, coloring and matching problems, automorphism group of a graph, generalizations of graphs, matrix methods, network problems. Applications to electrical networks, economics, and sociometry.]

[**IOR635—736 Game Theory I-II** Fall: IOR735. Spring: IOR736. Credit three hours a term. Three lecture-recitations. Prerequisite: Mathematics 411 or consent of instructor; first term is prerequisite to the second. Not offered 1975–76.
Two-person-zero-sum games; the minimax theorem, relationship to linear programming. Two-person-general-sum games. Noncooperative n-person games; Nash equilibrium points. Cooperative n-person games: the core, stable sets, Shapely value, bargaining set, kernel, nucleolus. Games without side payments. Games with infinite number of players. Economic market games. Mathematical techniques of game theory.]

IOR637 Dynamic Programming Fall. Credit three hours. Three lectures. Prerequisite: IOR260 or IOR660; IOR320 is desirable. L. E. Trotter, Jr.
Optimization of sequential or multistage decision processes based on the application of the dynamic programming principle of optimality. Theory, computation, and applications.

IOR640—741 Network Flows and Extremal Combinatorial Problems I-II Fall: IOR640, Spring: IOR741. Credit three hours a term. Three lecture-recitation periods. Prerequisite: consent of instructor; first term is prerequisite to the second.
D. R. Fulkerson.
The theory of flows in capacity-constrained networks and related areas in applied combinatorial mathematics. Topics include: maximum flow, feasibility criteria, minimum path, minimum cost flow, maximum dynamic flow, out-of-kilter algorithm, multiterminal flows, network synthesis, project cost curves, scheduling problems, set representatives, (0,1)-matrices, matchings, packing and covering problems, matroid partition and intersection, flows in infinite graphs, blocking systems.

IOR660 Introduction to Probability Theory with Engineering Applications Fall. Credit four hours. Three lectures, one recitation. N. U. Prabhu.
Covers the same topics as IOR260, but all lectures and computing sessions are independent of those for IOR260.

IOR661 Applied Stochastic Processes Spring. Credit four hours. Three lectures, one recitation. Prerequisite: a good first course in probability (e.g., IOR660 or Mathematics 471), or a similar degree of sophistication (e.g., IOR260 plus IOR361). H. M. Taylor, 3d.
An introduction to stochastic processes; a variety of applications of the basic theory. Topics are: second order processes; Markov chains and processes; diffusion processes, renewal theory and recurrent events; fluctuation theory; random walks; branching processes; Brownian motion; birth and death processes. Examples are drawn from queuing theory, population growth and other ecological models, inventory theory, etc.

IOR670 Introduction to Statistical Theory and Engineering Applications Spring. Credit four hours. Three lectures, one recitation. Prerequisite: IOR260 or IOR660. M. S. Taqqu.
Covers the same topics as IOR370, but all lectures and computing sessions are independent of those for IOR370.

IOR671 Intermediate Statistics Fall. Credit four hours. Three lectures, one recitation. Prerequisites: IOR370, IOR670, or consent of instructor. T. J. Santner.
Distributions of random variables arising in statistical inferences based on the linear model, including noncentral F and noncentral t distributions. Derivation of least square estimators and their properties; likelihood ratio tests. Applications to regression analysis and various Anova models; robustness properties.

IOR672 Statistical Decision Theory Spring. Credit three hours. Three lectures. Prerequisite: IOR471 or IOR670 or equivalent. L. I. Weiss.
The general problem of statistical decision theory and its applications. The comparison of decision rules; Bayes, admissible, and minimax decision rules. Problems involving a sequence of decisions over time, including sequential analysis. Use of the sample cumulative distribution function and other nonparametric methods. Applications to problems in the areas of inventory control, sampling inspection, capital investment, and procurement.

IOR674 Design of Experiments Spring. Credit four hours. Three lectures. Prerequisite: IOR671 or consent of instructor. R. E. Bechhofer.

Use and analysis of experimental designs such as randomized blocks and Latin squares, analysis of variance and covariance, factorial experiments, statistical problems associated with finding best operating conditions, response-surface analysis.

IOR680 Digital Systems Simulation Fall. Credit four hours. Two lectures, one recitation. Prerequisites: Computer Science ICS211 and IOR370, or consent of instructor. W. L. Maxwell.
The use of a program for a digital computer to simulate the operating characteristics of a complex system in time. Discussion of problems encountered in construction of a simulation program; synchronization and file maintenance, random-number generation, random-deviate sampling. Programming in simulation languages. Problems in the design of effective investigations using simulation; statistical considerations when sampling from a simulated process.

IOR682 File Processing (Same as Computer Science ICS632.) Spring. Credit four hours. Two lectures, one computing session. Prerequisite: Computer Science ICS211 or consent of instructor. R. W. Conway.

IOR738 Game Theory Seminar Spring. Credit three hours. Prerequisite: IOR736 or consent of instructor. L. J. Billera.
A seminar in which students read and report on current papers of interest in game theory, primarily in the area of *n*-person cooperative theory.

[**IOR739 Selected Topics in Mathematical Programming** Spring. Credit three hours. Three lecture-recitations. Prerequisites: IOR630 and consent of instructor. Not offered 1975–76.
Current research topics in mathematical programming.]

[**IOR761 Advance Queuing Theory** Fall. Credit three hours. Three lectures. Prerequisite: IOR660 or equivalent. Not offered 1975–76.
A study of stochastic processes arising in a class of problems including congestion, storage, dams, and insurance. The treatment will be self-contained. Transient behavior of the processes will be emphasized. Heavy traffic situations, including large-time approximations such as diffusion, will be investigated.]

[**IOR764 Stochastic Control** Spring. Credit three hours. Three lectures. Prerequisite: consent of instructor. Not offered 1975–76.
The problem of stochastic control. Necessary and sufficient conditions for optimality. Stationarity. Computational algorithms. Applications to problems in operations research, including queues and inventories.]

[**IOR769 Selected Topics in Applied Probability** Fall. Credit three hours. Three lectures. Prerequisites: IOR661 and consent of instructor.Not offered 1975–76.
Selected topics in applied probability for advanced students. Topics will be chosen from current literature and research areas of the staff.]

IOR773 Statistical Multiple-Decision Procedures Fall. Credit three hours. Three lectures. Prerequisite: IOR764 or consent of instructor. R. E. Bechhofer.
The study of multiple-decision problems in which a choice must be made among two or more courses of action. Statistical formulations of the problems. Fixed-sample size, two-stage, and sequential procedures. Special emphasis on applications to ranking problems involving choosing the "best" category where goodness is measured in terms of a particular parameter of interest. Recent developments.

[**IOR774 Nonparametric Statistical Analysis** Spring. Credit three hours. Three lectures. Prerequisite: IOR670 or consent of instructor. Not offered 1975–76.
Estimation of quantiles, c.d.f.s. and p.d.f.s. Properties of order statistics and rank-order statistics. Hypothesis testing in one- and two-sample situations. Large sample properties of tests and asymptotic distributions of various test statistics.]

IOR779 Selected Topics in Statistics Either term. Credit three hours. Three lectures. Prerequisite: IOR670 or consent of instructor. T. J. Santner, L. I. Weiss.
Selected topics chosen from such fields as nonparametric statistical methods, sequential analysis, multivariate analysis.

IOR789 Selected Topics in Information Processing (Same as Computer Science ICS733.) Fall. Credit four hours. Two lectures, one computing session. Prerequisites: Computer Science ICS314 and IOR682, or consent of instructor. E. K. Clemons.
Selected topics in the design and optimization of record storage and file accessing methodology using operations research techniques.

IOR890 Special Investigations in Industrial Engineering and Operations Research Either term. Credit and sessions as arranged. Offered to students individually or in small groups. Registration must be made with the registration officer of the School.
Study, under direction, of special problems in the field of Industrial Engineering and Operations Research.

IOR891 Operations Research Graduate Seminar Fall and spring. Credit one hour each term. Staff.
A weekly 1½ hour seminar devoted to presentation, discussion, and study of research in the Field of Operations Research. Distinguished visitors from other universities and institutions, both domestic and foreign, and faculty members and advanced graduate students of the Department and the University speak on topics of current interest.

IOR893—894 Industrial Engineering Graduate Seminar Fall and spring. Credit one hour each term. Staff.
A weekly meeting to discuss assigned topics and hear presentations of the state of the art from practitioners in the field.

IOR898 Project Laboratory Fall. Credit one hour. Staff.
A weekly meeting for review of case studies and project planning, analysis, and management.

IOR899 Project Fall and spring. Credit variable. A project must be completed by each candidate for the professional Master of Engineering degree.
Project work requires the identification, analysis, and design of feasible solutions to some loosely structured systems engineering problem. The solution must be defended on sound engineering and economic grounds.

Materials Science and Engineering

Undergraduate Courses

ITE201 Elements of Materials Science Spring. Credit three hours.
Relations between atomic structure and macroscopic properties of such diverse materials as metals, ceramics, and polymers. Properties discussed include magnetism, superconductivity, insulation, semiconductivity, mechanical strength, and plasticity. Applications to microelectronics, desalinization by reverse osmosis, superconducting power transmission lines, synthetic bones and joints, etc. Extensive use of modern educational techniques, including slides, audiotutorial systems, movies.

ITE261 Introduction to Mechanical Properties of Materials Either term. Credit three hours. Two lectures, one recitation or laboratory.
See description under Division of Basic Studies.

ITE262 Introduction to Electrical Properties of Materials Spring. Credit three hours. Two lectures, one recitation or laboratory.
See description under Division of Basic Studies.

ITE331 Structure and Properties of Materials Fall. Credit four hours. Lectures and laboratory.
The mostly widely used techniques to characterize and investigate materials such as metals, glasses, ceramics, and polymers; associated laboratory work teaches the use of the optical microscope and x-ray diffraction, and exposes the student to transmission electron microscopy and the use and application of the scanning electron microscope. Discussion of how knowledge of the microscopic structure of materials obtained with these experimental techniques can be used to predict and understand important engineering properties such as hardness, strength, and formability of known materials, and how this understanding also provides guidelines for the development of new materials.

ITE333 Research Involvement I Fall. Credit three hours.
Semi-independent research project in affiliation with a faculty member and research group of the department. Approval of department required.

ITE334 Research Involvement II Spring. Credit three hours.
May be a continuation of ITE333 or a one-term affiliation with a research group. Approval of department required.

ITE335 Thermodynamics of Condensed Systems Fall. Credit three hours. Three lectures.
The various phases of materials and the changes that occur within materials when temperatures and pressures change are considered by developing the laws of thermodynamics and applying them to different systems. The use of phase diagrams to predict the phase(s) of an alloy system at any given temperature and pressure in order to understand basic aspects of heat treatment such as the hardening of aluminum alloys and the quenching of steels. Phase transformations under conditions of rapid cooling (quenching) and their influence on hardness. Guidelines for the optimal heat treatment of steels.

ITE336 Kinetics, Diffusion, and Phase Transformations Spring. Credit three hours. Three lectures.
Introduction to absolute rate theory, atomic motion, and diffusion. Applications to nucleation and growth of new phases in vapors, liquids, and solids; solidification, crystal growth, oxidation and corrosion, radiation damage, recrystallization, gas-metal reactions.

ITE337 Materials and Manufacturing Processes (Same as Mechanical and Aerospace Engineering IMM311.) Either term. Credit three hours. Two lectures, one laboratory. May be taken in addition to ITE261. Prerequisite: IAK221.
Comprehension of material structures. Physical and metallurgical properties of materials, and their control by mechanical and metallurgical means. Conventional and unconventional manufacturing processes. Emphasis is placed on the applications of the knowledge learned in core courses and the correlations among design, material properties, and processing methods.

ITE338 Analysis of Manufacturing Processes (Same as Mechanical and Aerospace Engineering IMM612.) Spring. Credit three hours. Three recitations. Prerequisite: ITE337.
Analytical treatment of the processes of material removal and plastic deformation, from the interdisciplinary viewpoints of mechanics, thermodynamics, and metallurgy. Emphasis is placed equally on conventional and unconventional processes involving ultrasonic, high energy beam, electric discharge, and electrochemical energy sources. Also, economic analysis of production system and machine tool dynamics.

ITE440 Macroprocessing of Materials Spring. Credit three hours. Three lectures, occasional laboratory.
Control of chemical composition through smelting, reaction, and refining processes; applications to iron and steel, aluminum, refractories, etc. Shape control; casting and solidification, welding; mechanical shap-

ing through rolling, drawing, etc. Deformation and annealing, textures; relation to material properties. Thermomechanical treatments for control of material properties.

ITE441 Microprocessing of Materials Fall. Credit three hours. Three lectures, occasional laboratory.
The materials technology of electronic and magnetic devices; single crystals as well as thin films. Growth and purification (zone refining) of semiconducting crystals; doping procedures, including ion implantation; composition control; oxide growth; photoetching. Preparation of thin films by vapor deposition; sputtering; plating; evaluation of film geometry and composition. Material aspects of recent devices (superlattice growth, magnetic amorphous bubbles, etc.).

ITE443–444 Senior Materials Laboratory Either term. Credit three hours.
Experiments are available in structural studies, properties of materials, deformation and plasticity, mechanical and chemical processing, phase transformation, surface physics, etc.

ITE445 Electrical and Magnetic Properties of Materials Fall. Credit three hours. Three lectures.
An introduction to electrical and magnetic properties of materials with emphasis on structural aspects. Classification of solids, charge and heat transport in metals and alloys, semiconductors and insulators, principles of operation and fabrication of semiconductor devices, behavior of dielectric and magnetic materials, magnetic devices, phenomenological description of superconducting materials.

ITE446 Mechanical Properties of Materials Spring. Credit three hours. Three lectures.
The mechanical properties of materials and how they can be understood and analyzed in terms of microscopic irregularities (lattice defects) in perfect regular crystals. The general relation between stress and strain; the concept of equivalent stresses and strains. How the concept of local defects can explain many aspects of plastic flow, creep, fatigue, and rupture in classical and new engineering materials. Application of these concepts to the development of improved materials.

ITE447 Applied Metallurgy (Same as Mechanical and Aerospace Engineering IMM613.) Credit three hours. Two lectures, one laboratory. Prerequisite: IMM311 or ITE261 or permission of instructor.
W. W. Carson.
Designed to aid engineers and material scientists in the design, selection, and use of metals and alloys. Emphasis on theory and practice of extractive, physical, and mechanical metallurgy. Additional topics include corrosion principles and control, metallurgical failure analysis and prevention, nondestructive testing, metallurgical examination techniques, soldering, brazing, welding, powder metallurgy, and computer applications to metallurgy.

ITE448 Current Topics in Materials Spring. Credit three hours. Three lectures.
oordinated lectures on topics of current interest, such as biomaterials, fuel cells, composite materials, materials problems in power generation and distribution systems, stress corrosion cracking, etc.

ITE449 Introduction to Ceramics Fall. Credit three hours. Three lectures. Prerequisite: ITE261 or consent of instructor.
Designed to develop an understanding of ceramic materials and processes for engineering applications. Some raw materials and methods of forming. The crystallographic nature of some ceramics, and structural imperfections that can occur. Atomic and ionic motions in crystalline ceramics and their relation to properties and forming methods (such as sintering). Mechanical properties, such as cracking, in terms of microscopic mechanisms. The properties of some new ceramic materials, such as silicon nitride and barium titanate, in special applications.

Graduate Program Courses

ITE701 Topics in Thermodynamics and Kinetics Fall. Credit three hours.
The following topics are treated for condensed systems: free energy and phase equilibria; thermodynamics of solutions; interfaces; thermodynamics under applied fields; irreversible thermodynamics; reaction rate theory and diffusion.

ITE702 Phase Transformations Spring. Credit three hours. Prerequisite: ITE701 or equivalent.
Nucleation theory. Growth theory. Formal theory of nucleation and growth transformation. Spinodal decomposition. Diffusionless transformations. Discussions of topics such as crystal growth from the vapor, solidification, eutectic transformations, solid state precipitation, eutectoid transformations, martensitic transformations with emphasis on the heat treatment of steels, and transformations in polymers and glasses. At the level of *Phase Transformations,* American Society of Metals, 1970.

ITE703 Elasticity and Physical Properties of Crystals Fall. Credit three hours.
Elastic stress and strain, constitutive relations between stress and strain, elastic wave propagation in crystals, stress fields of dislocations, thermal stresses, stresses at cracks, generalized tensor representation of reversible physical properties of crystals, irreversible thermodynamics, the Onsager relations and transport phenomena in crystals. At the level of *Physical Properties of Crystals* by Nye.

ITE704 Plastic Flow and Fracture of Materials Spring. Credit three hours. Prerequisite: ITE703 or equivalent.
Introduction to the theory of dislocations. Strain hardening. Dislocation dynamical treatment of yield and flow. Polycrystalline hardening. Interaction of interstitial solute atoms with dislocations. Solution hardening. Two-phase hardening. Time- and temperature-dependent deformation. Dislocation models for cleavage of crystals. Viscosity and visco-elastic behavior. Theories of rubber elasticity. Newtonian and nonlinear viscous flow. Creep and creep rupture. Ductile fracture and the fracture of rubber. Fatigue. At the

level of *Elementary Dislocation Theory* by Weertman, and Weertman review articles in *Progress in Materials Science,* and various conference reports.

ITE706 Principles of Diffraction (Same as Applied and Engineering Physics IP711.) Fall. Credit three hours.
Broad introduction to diffraction phenomena as applied to solid state problems. Production of neutrons and x-rays, scattering and adsorption of neutrons, electrons, and x-ray beams. Diffraction from two- and three-dimensional periodic lattices. Crystal symmetry, Fourier representation of scattering centers, and the effect of thermal vibrations on scattering. Phonon information from diffuse x-ray and neutron scattering and Bragg reflections. Standard crystallographic techniques for single crystals and powders. Diffraction from almost-periodic structures, surface layers, gases, and amorphous materials. Survey of dynamical diffraction from perfect and imperfect lattices. Techniques for imaging structural defects. At the level of *Optical Principles of the Diffraction of X-rays* by R. W. James, *X-Ray Diffraction* by B. E. Warren, *Electron Diffraction* by Vainshtein, and *Electron Microscopy of Thin Crystals* by Hirsch, et al. Lectures accompanied by experiments on fluorescence and polarization of x-rays, diffractometer measurements of vibrational amplitudes in crystals, natural widths of emission lines, and identification of crystal structures and crystal orientation by back reflection techniques.

ITE707 Solid State Physics (Same as Physics 635, Solid State Physics I.) Fall.
An intermediate course in solid state physics including studies in the electron structure of solids, their classification, and, in the case of metals, band theory and Fermi surfaces. Topics also include the equilibrium and transport properties of solids, the classical and quantum harmonic crystal, and the fundamentals of semiconducting solids. At the level of *Solid State Physics* by Ashcroft and Mermin, or *Introduction to Solid State Physics* (4th edition) by Kittel.

Other Graduate Courses

ITE553–554 Special Project Fall and spring. Credit six hours.
Research on a specific problem in the materials area.

ITE712 Selected Topics in Diffraction (Same as Applied and Engineering Physics IP712.) Spring. Credit three hours.
Ewald-von Laue dynamical theory applied to x-ray and high energy electron diffraction in solids. Thermal scattering and measurement of phonon dispersion, frequency spectrum, interatomic force constants, Debye temperatures, and vibrational amplitudes. Diffuse scattering, short- and long-range order, precipitation in solids, point defects.

ITE714 Electron Microscopy Spring. Credit three hours.
Electron optics. Kinematical theory of diffraction with applications to the imaging of crystal defects. Dynamical theory of diffraction as applied to the calculation of images of various defects. Interpretation and analysis of electron diffraction patterns. Application of the stereographic projection to problems in microscopy. Applications of dark field microscopy. Instruction in the use of the microscope.

ITE716 The Effects of Radiation on Materials Either term. Credit three hours. Three lectures.
Cross section for atom displacement; orientation dependence of the threshold energy; interatomic potentials; the atomic collision cascade; focusing of atomic collisions; mass transport along collision spectra within a cascade; range concepts and measurements in polycrystalline and single crystal solids; channeled particles and the effect of crystal imperfections on the range; Rutherford scattering and channeling and their application to the lattice location of impurity atoms; sputtering of single and polycrystalline metals; recovery mechanisms for radiation damage; void formation in metals irradiated to high fluences and the problem of swelling in liquid metal fast breeder reactors. At the level of *Defects and Radiation Damage in Metals* by M. W. Thompson; *The Observation of Atomic Collisions in Crystalline Solids* by R. S. Nelson; *Ion Bombardment of Solids* by G. Carter and J. S. Colligon; and selected papers and review articles.

ITE762 Physics of Solid Surfaces (Same as Applied and Engineering Physics IP762.) Spring. Credit three hours. Prerequisites: ITE701 and some knowledge of solid state physics.
Equilibrium thermodynamics and statistical mechanics of interfaces. Atomic structure of surfaces in equilibrium. Surface fields, dipoles, and defects in insulators. Electronic and vibrational properties of surfaces. Surface barriers and work functions, surface vibrational and electronic states. Kinetic processes at surfaces. Mass and charge transport. Condensation and evaporation processes. Experimental techniques. Materials drawn from research papers and various review articles in journals such as *Progress in Materials Science, Advances in Chemistry,* and *Solid State Physics.*

ITE765 Amorphous and Semicrystalline Materials Spring. Credit three hours.
Topics related to the science of the amorphous state selected from within the following general areas: structure of liquids and polymers; rheology of elastomers and glasses; electrical, thermal, and optical properties of amorphous materials. Presented at the level of *Modern Aspects of the Vitreous State* by Mackenzie, "Glass Transitions" by Shen and Eisenberg in *Progress in Solid State Chemistry,* and *The Physics of Rubberlike Elasticity* by Treloar.

ITE767 Electrical and Magnetic Properties of Materials Spring. Credit three hours. Prerequisite: Physics 454 or equivalent.
Electronic transport properties of metals and semiconductors, semiconductor devices, optical and dielectric properties of insulators and semiconductors, laser materials, dielectric breakdown, structural aspects of superconducting materials, ferromagnetism and magnetic materials. At the level of *Physics of Semiconductor Devices* by Sze, *Ferromagnetism* by Bozworth, and current review articles.

ITE768 Theory of Crystal Defects Fall. Credit three hours. Prerequisites: ITE701 and ITE703 or equivalent.
The structure and properties of point, line, and planar crystal defects treated from a fundamental point of view. Thermodynamics and kinetics of point defects. Atomistic and continuum theories of dislocations. Thermodynamic treatment of grain boundaries. Structure of grain boundaries. Emphasis given throughout to interactions between the various types of defects and to their roles in important phenomena such as diffusion, precipitation, plasticity, radiation damage. At the level of *Point Defects and Diffusion* by Flynn, *Theory of Dislocations* by Hirth and Lothe, and *High Angle Grain Boundaries* by Gleiter and Chalmers.

ITE769 Ceramic Materials Fall. Credit three hours. Prerequisites: ITE701 and some familiarity with crystal structures.
Crystal structure and bonding of typical ceramic materials; structure of silicate and nonsilicate glasses; imperfections in oxides; point defects and point defect chemistry, line defects, extended defects; diffusion in stoichiometric and nonstoichiometric ceramics; phase transformations; equilibrium and nonequilibrium phases; grain growth and sintering; plastic deformation and creep; topics from research papers. At the level of *Introduction to Ceramics* by Kingery, *Ionic Crystals, Lattice Defects and Nonstoichiometry* by N. N. Greenwood, and selected research papers.

Mechanical and Aerospace Engineering

The courses in mechanical and aerospace engineering are listed under the following headings: *General, Engineering Design, Mechanical Systems and Analysis, Materials Processing, Transportation, Biomechanics, Aerospace Engineering, Fluid Mechanics, Heat Transfer,* and *Power, Advanced Thermodynamics, and Combustion.*

General

IMG101 Naval Ship Systems Spring. Credit three hours. Open to freshmen and sophomores only.
An introduction to primary ship systems and their interrelation. Basic principles of ship construction, stability, propulsion, control, internal communications, structure, and other marine systems.

IMG302 Technology and Society—A Historical Perspective Spring. Credit three hours. Three lecture-discussions. Prerequisite: upperclass standing in engineering or permission of instructor. Approved as a liberal elective for undergraduates in engineering. B. J. Conta.
An introduction to the history of technology and its relationship to society. Emphasis will be upon the interactions between technology and the corresponding economic, social, and political developments of the period, rather than upon the internal history of technology. The period of major interest will be the nineteenth and twentieth centuries. Both the material abundance and the explosive problems of the twentieth century had their origins in two dramatic developments of the nineteenth century. One was the emergence of the Watt steam engine as a general purpose prime mover and the vast increase in available power it made possible by the exploitation of the thermal energy of wood and the fossil fuels. A second and less obvious development was a change in the technical motivation. Technology changed from a response to the needs of man (necessity as the mother of invention) to a response to the possibilities of science (invention as the mother of necessity—the technological imperative).

IMG208 The Role of Energy in Society Spring, on demand. Credit three hours. Prerequisite: consent of instructor.
A seminar-format course including: patterns of energy consumption; United States and world comparisons; fuel resources; technology of fuel extraction, energy conversion, and utilization; energy policies and regulations; environmental conflict; limits to growth.

IMG221 Thermodynamics Either term. Credit three hours. Three recitations. Prerequisites: Mathematics 191 and 192, Physics 112.
See description under Division of Basic Studies.

IMG325 Mechanical Design and Analysis Either term. Credit four hours. Three recitations, one laboratory. Prerequisites: IAK231 and IAK221.
Application of the principles of mechanics and materials to problems of analysis and design of mechanical systems. Topics considered vary from year to year and range from traditional discipline-oriented work to work cutting across several disciplines. Laboratory considers open-ended design problems. Use of the digital computer for design problems is required.

IMG453 Mechanical Engineering Laboratory Fall. Credit four hours. One lecture, two laboratories. Prerequisites: IMG325, IMG221, IMF323, and simultaneous registration in IMS326 and IMH324.
Laboratory exercises in instrumentation, techniques, and methods in mechanical engineering. Measurement of pressure, temperature, heat flow, mass transfer, displacement, force stress, strain, vibrations, noise, etc. Use of electronic instruments and fast-response sensors for steady and transient states. Use of density-sensitive optical systems. Error analysis in experimental determinations.

IMG483 Reliability Spring. Credit three hours. Prerequisite: IOR260 or IOR270 or equivalent.
S. L. Phoenix.
An introduction to reliability concepts and methods in engineering and the probabilistic models on which they are based. Combinatorial reliability, hazard function concepts, system reliability, system hazard rate in terms of element hazard rate, static material strength models, Poisson based flaw models, fibre bundle

models, strength loss estimation, failure data interpretation. Probabilistic fatigue models, probabilistic interpretation of S-N curves, P-S curves, random fatigue crack growth models, cumulative damage models.

IMG654 Environmental Control Fall. Credit three hours. Prerequisites: courses in thermodynamics, fluid mechanics, and heat transfer. D. G. Shepherd.
Environmental living systems; heating, cooling, and air conditioning. Refrigeration and cryogenic systems and applications. Artificial environments and life-support systems for space and underwater. Production of high vacuum, pressure, temperature, and velocity for simulation of special environments; problems of zero gravity.

IMG656 Energy and Fluid Systems Laboratory Fall. Prerequisite: IMG453 or equivalent.
Individually offered experimental studies. The time allotted, and the number of students accepted for each experiment will be specified by the instructor in each case. Available experiments will range from performance testing of engine components to studies of laser interferometry.

IMG790 Mechanical Engineering Design Project Both terms. Credit three hours each term. Intended for students in the M.Eng. (Mechanical) degree program.
Design of an engineering system or a device of advanced nature. Projects to be carried out by individual students or by small groups with individual assignments culminating in an engineering report by each student. In some cases the project is carried out in collaboration with an external organization, such as an industrial company, research laboratory, or public agency, whose representatives suggest current problems and review the final designs.

IMG791 Mechanical and Aerospace Engineering Research Conference Either term. Credit one hour. For graduate students involved in research projects. Short presentations on research in progress by students and staff.

IMG799 Mechanical and Aerospace Engineering Colloquium Throughout the year. Credit one hour a term. All students and staff invited to attend. Registration for credit limited to graduate students.
Lectures by Cornell staff members, graduate students, and visiting scientists on topics of interest in mechanical and aerospace science, especially in connection with new research.

IMG890 Research in Mechanical and Aerospace Engineering Credit arranged. Prerequisite: candidacy for M.S. degree in mechanical or aerospace engineering, or approval of the director.
Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the staff.

IMG990 Research in Mechanical and Aerospace Engineering Credit arranged. Prerequisite: candidacy for Ph.D. degree in mechanical or aerospace engineering or approval of the director.
Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the staff.

Engineering Design

IMD464 Design for Manufacture Fall. Credit three hours. Three recitations. Prerequisite: IMM311 or ITE261, or concurrent enrollment in IMM311, or consent of instructor. R. L. Wehe.
Design of castings, forgings, stampings, and weldments; unconventional processes. Design for heat treatment, machining, and assembly; selection of materials; dimensioning and fits, jigs and fixtures. Joints, fasteners, and shaft mountings and connections. Specifications for manufacturing and maintenance to minimize fatigue failures and improve reliability; beneficial prestressing; improving the distribution of loads and deflections. Seals and lubrication systems. Components and circuits for fluid power and controls. Short design problems.

IMD663 Mechanical Components Spring. Credit three hours. Three recitations. Prerequisite: IMG325 or equivalent.
Advanced analysis of machine components and structures. Application to the design of new configurations and devices. Selected topics from the following: lubrication theory and bearing design, fluid couplings, torque converters, speed-control devices, shells, thick cylinders, elastic foundation theory, design of pressure vessels, rotating disks, fits, elastic-plastic design, thermal stresses, creep and relaxation, impact, indeterminate and curved beams, plates, contact stresses, gears, and rolling bearings.

IMD672 Experimental Methods in Machine Design Fall. Credit three hours. One recitation, two laboratories. Prerequisite: IMG325 or equivalent. R. M. Phelan.
Investigation and evaluation of methods used to obtain design and performance data. Techniques of photoelasticity, strain measurement, photography, vibration and sound measurements, and development techniques as applied to machine design problems.

IMD680 Design of Complex Systems Fall, on demand. Credit three hours. Two meetings of two hours a week. Prerequisite: consent of instructor. R. L. Wehe.
A seminar course relying heavily on student participation in discussing frontier problems such as systems for space and underwater exploitation, salt water conversion, and transportation. Determination of specifications for these systems to meet given needs. Critical discussion of possible solutions based on technical as well as economic and social considerations. Reports that set forth recommendations and the reasoning leading to them will be required.

IMD690 Special Investigations in Mechanical Design Either term. Credit arranged. Prerequisite: consent of supervising professor.
Individual work or work in small groups under gui-

dance in the design and development of a machine or in the analysis of experimental investigation of a machine or component.

IMD692 Special Topics in Engineering Design Either term. Credit one hour or more. Lectures on a topic of special interest. Hours to be arranged. Prerequisite: consent of instructor.
Series of lectures by staff members and visiting staff on subjects of current interest. Topics will be announced before the beginning of the term. More than one topic may be taken if offered.

Mechanical Systems and Analysis

IMS326 Systems Dynamics Either term. Credit four hours. Three recitations, one laboratory. Prerequisite: IMG325.
Consideration of the dynamic behavior of systems with emphasis on modeling and analysis techniques and their application. Discipline-oriented topics include analog- and digital-computer simulation; frequency and transient response of linear systems, scalar and vector-matrix models, and dynamic measurement of physical quantities. Laboratories include physical experiments, computer simulations, and design of systems for specified dynamic performance. Applications are drawn chiefly from vibration and control systems.

IMS389 Computer-Aided Design Spring. Credit three hours. Two lecture-recitations, one computing laboratory. Open to juniors and seniors. Staff.
A broad introduction to computational methods in design. Considerable practical experience in programming large and small digital computers. Interactive computing. Selected applications of numerical methods to problems in mechanical design. Case studies or large programs and problem-oriented languages for system simulation, design optimization, computer graphics. Term project.

IMS677 Mechanical Vibrations Spring. Credit three hours. Two recitations, one laboratory. Open to qualified undergraduates. Prerequisite: IMS326 or equivalent. R. M. Phelan.
Further development of vibration phenomena in single-degree and multidegree of freedom linear and nonlinear systems, with emphasis on engineering problems involving analysis and design. Also gyroscopic effects, branched systems, random vibrations, impact and transient phenomena, isolation of shock vibration, and noise and its reduction. Impedance, matrix, and numerical methods. Analog- and digital-computer solutions and laboratory studies.

IMS678 Automatic Control Systems Fall. Credit three hours. Two recitations, one laboratory. Open to qualified undergraduates. Prerequisite: IMS326 or equivalent.
Further development of the theory and implementation of feedback control systems with particular emphasis on the application of pseudo-derivative-feedback (PDF) control concepts to linear and nonlinear systems. Analog-computer simulation and laboratory studies of electromechanical, pneumatic, and hydraulic components and systems.

IMS679 Computer Simulation and Analysis of Dynamic Systems Spring. Credit three hours. Three recitations. Open to qualified undergraduates by permission of instructor. Some introductory acquaintance with systems dynamics and digital programming areas is assumed.
Modeling and representation of physical systems by systems of ordinary differential equations in vector form. Applications from diverse fields. Simulation diagrams. Analog and digital simulation by direct integration. Problem-oriented digital-simulation languages (e.g., CSMP). Digital analysis of stability and response of large linear systems.

IMS682 Hydrodynamic Lubrication Spring. Credit three hours. Three recitations.
Designed to acquaint those having a general knowledge of solid and fluid mechanics with the special problems and literature currently of interest in various fields of hydrodynamic lubrication. General topics include equations of viscous flow in thin films, self-acting and externally pressurized bearings with liquid and gas lubricant films, bearing-system dynamics, and digital and analog computer solutions. Also, selected special topics.

IMS685 Optimum Design of Mechanical Systems Spring. Credit three hours. Three recitations. D. L. Bartel.
The formulation, as optimization problems, of design problems frequently encountered in mechanical systems. Emphasis is on the choice of the design objective function and the constraints. Finite and infinite dimensional design problems. Theory and application of methods of mathematical programming to the solution of optimum design problems. Examples will be drawn from the structures and machine components frequently encountered in mechanical systems.

IMS690 Special Investigations in Mechanical Systems Either term. Credit arranged. Permission required.
Individual work or work in small groups under guidance in studies in a special field of mechanical systems.

IMS770 Advanced Mechanical Analysis Fall. Credit three hours. Three recitations.
Advanced topics in mechanical design. Selected topics from design optimization, finite-element methods, design reliability, advanced kinematics, systems analysis, computer-aided design, advanced strength of materials.

IMS771 Computational Methods of Mechanical Analysis Spring, offered on demand. Credit three hours. Prerequisite: IMS761 or equivalent. Staff.
Modern computer-based methods for mechanical design analysis as applied to motion analysis of linkages, stress-strain and load deflection analysis of mechanical structures, pressure-flow analysis of bearing lubricant film systems. Methods include finite elements, transfer matrices, etc.

Materials Processing

IMM311 Materials and Manufacturing Processes (Same as Materials Science and Engineering ITE337.) Either term. Credit three hours. Two lectures, one laboratory. May be taken in addition to ITE261. Prerequisite: IAK221.
Comprehension of material structures. Physical and metallurgical properties of materials, and their control by mechanical and metallurgical means. Conventional and unconventional manufacturing processes. Emphasis is placed on the applications of the knowledge learned in core courses and the correlations among design, material properties, and processing methods.

IMM612 Analysis of Manufacturing Processes Spring. Credit three hours. Three recitations. Prerequisite: IMM311. K. K. Wang.
Analytical treatment of the processes of material removal and plastic deformation, from the interdisciplinary viewpoints of mechanics, thermodynamics, and metallurgy. Emphasis is placed equally on conventional and unconventional processes involving ultrasonic, high-energy beam, electric-discharge, and electrochemical energy sources. Also economic analysis of production-system and machine-tool dynamics.

IMM613 Applied Metallurgy (Same as Materials Science and Engineering ITE447.) Credit three hours. Two lectures, one laboratory. Prerequisite: IMM311 or ITE261 or permission of instructor. W. W. Carson.
Designed to aid engineers and material scientists in the design, selection, and use of metals and alloys. Emphasis on theory and practice of extractive, physical, and mechanical metallurgy. Additional topics include corrosion principles and control, metallurgical failure analysis and prevention, nondestructive testing, metallurgical examination techniques, soldering, brazing, welding, powder metallurgy, and computer applications to metallurgy.

IMM614 Numerical Control in Manufacturing Fall. Credit three hours. Three recitations. K. K. Wang.
Introduction of numerical control technology in manufacturing. Principles of conventional numerical control, adaptive control, and direct computer control systems of machine tools. Manual and computer-aided programming methods for numerically controlled machines. Economic aspects and manufacturing systems involving numerical control facilities.

IMM690 Special Investigations in Materials Processing Either term. Credit to be arranged. Permission required for registration.
Independent study of selected topics concerned with analytical or experimental investigation of manufacturing processes. Design, manufacture, and test of a machine or a component to be used for materials processing. Topics will include production systems, quality assurance, metrology, or machine tools, in ancordance with individual interests. Work will be carried out individually or, for relatively large-scale projects, in small groups.

Transportation

IMT305 Introduction to Aeronautics Fall. Credit three hours. Open to upperclass engineers and others by consent of the instructor. D. A. Caughey.
An introduction to atmospheric flight vehicles. Principles of incompressible and compressible aerodynamics, boundary layers, and wing theory. Propulsion systems, including analysis of engine types, propellers, fans, and rotors. Aircraft performance: maximum speed, rate of climb, range and endurance, takeoff and landing; turning performance; maneuver and gust loads; and elements of stability and control.

IMT486 Automotive Engineering Spring. Credit three hours. Prerequisite: IMG325.
Selected topics in the analysis and design of vehicle components and vehicle systems. Emphasis is on the automobile, particularly with regard to powerplant, driveline, brakes, suspension, and structure. Other vehicle types, including rapid transit and recreational vehicles, may be considered.

[**IMT606 Aerospace Propulsion Systems** Spring, alternate years. Credit three hours. Three recitations. Prerequisite: IMG221, IMF323, or consent of instructor. D. G. Shepherd. Not offered 1975–76.
Application of thermodynamics and fluid mechanics to the design and performance of thermal-jet and rocket engines in the atmosphere and in space. Mission analysis in space as it affects the propulsion system. Consideration of auxiliary power supply; study of advanced methods of space propulsion.]

IMT607 Dynamics of Flight Vehicles Spring. Credit three hours. Prerequisite: IAK231 and IMT305, or consent of instructor. D. A. Caughey.

IMT687 Dynamics of Vehicles Fall. Credit three hours. Prerequisites: IAK221 and IAK231 or equivalents, and consent of instructor.
Intended as an introduction to the dynamics of automobiles and trucks. Emphasis is on the handling behavior of the automobile. Tire theory and suspension analysis. Also, articulated vehicle handling, motorcycle dynamics, and vehicle safety.

Biomechanics

IMB665 Biomechanical Systems—Analysis and Design Spring. Credit three hours. Three recitations. Prerequisites: IAK221, IAK231. D. L. Bartel.
Selected topics from the study of the human body as a mechanical system. Emphasis on the modeling, analysis, and design of biomechanical systems frequently encountered in orthopedic surgery and physical rehabilitation. Investigation of normal and impaired biomechanical systems. Analysis and design of assistive (orthotic) and replacement (prosthetic) devices for impaired biomechanical systems. Analysis and design of man/machine systems used in orthopedic surgery and physical rehabilitation.

IMB690 Special Investigations in Biomechanical Systems. Either term. Credit arranged. D. L. Bartel. Independent study of current problems involving the analysis and design of biomechanical systems. In most cases the investigations will involve collaboration with personnel from medical facilities. Work will be carried out individually or, for relatively large-scale projects, in small groups.

Aerospace Engineering

IMA602 Theoretical Aerodynamics I Fall. Credit three hours. Prerequisite: IMF632–633 or equivalent. Intended for graduate students interested in fluid dynamics or aerodynamics research. A. R. George. Laplace's equation. Source, sink, and doublet. Vortices. Biot-Savart theorem, the flow field of a vortex. Spherical and cylindrical harmonics. Methods of singularity distributions. Complex-variable methods. Wing theory. Acoustics. Compressible flows, subsonic and supersonic. Shock waves. Hypersonic flow. Rotational flows. Magnetohydrodynamics. Flow in the boundary layer, Prandtl theory. Heat transfer; separation.

IMA603 Theoretical Aerodynamics II Spring. Credit three hours. Prerequisite: IMF632–633 or equivalent. D. A. Caughey.
Basic equations; fundamental theorems; normal shock waves. Linear and nonlinear small-disturbance equations. Linearized theory of two-dimensional and axisymmetric flows; three-dimensional wings; supersonic area-rule. Exact theories; oblique shock waves and shock wave interactions; method of characteristics; conical flows; hodograph transformation. Improvements in the linearized theory; thickness and Mach number expansions; second-order supersonic flow; sonic boom theory; shock wave interactions. Transonic flow; fundamental equation and similitudes; transonic area-rule; nozzle flows; airfoil design.

IMA611 Physics of Fluids I Fall. Credit three hours. This course may be taken by itself, or may be followed by IMA612. F. C. Gouldin.
Fundamental treatment of fluid properties, primarily from a microscopic viewpoint, providing an understanding necessary for advanced study of combustion, air pollution, gas dynamics, and related areas. Kinetic theory of gases; BGK model equation, transport coefficients, mean free path, conservation equations. Chemical kinetics and chemical thermodynamics. Statistical mechanics of noninteracting particles: Fermi-Dirac, Bose-Einstein, and Maxwell-Boltzmann statistics, partition functions, specific heat of gases. Quantum mechanics: atomic structure, rotational and vibrational energy levels. At the level of *Introduction to Physical Gas Dynamics* by Vincenti and Kruger, and *The Dynamics of Real Gases* by Clarke and McChesney.

IMA612 Physics of Fluids II Spring, on demand. Credit three hours.
Molecular structure: bonding theory, heats of reaction. Atomic and molecular spectroscopy; applications to pollution. Nonequilibrium statistical mechanics: Boltzmann equation, H-theorem, review of Hilbert-Enskog-Chapman theory, fluctuations, Onsager's relations. Radiative transfer; lasers. At the level of *The Dynamics of Real Gases* by Clarke and McChesney, and *Elementary Statistical Physics* by Kittel.

IMA613 Gasdynamics Spring, on demand. Credit three hours. E. L. Resler, Jr.
Strong shock waves and their use in the production and study of high-temperature gases. High-temperature chemical kinetics and its application to hypersonic external flows, rocket internal flows, and other phenomena of current interest. Chemical relaxation effects of flow fields and the method of characteristics including chemical reactions. Experimental techniques.

IMA621 Introductory Plasma Physics (Equivalent to Electrical Engineering IEE681.) Fall, alternate years. Credit three hours.
Intended to be a first course in plasma physics and includes: plasma state, particle orbits in electric and magnetic fields, adiabatic invariants, Coulomb scattering, transport phenomena, plasma oscillations and waves, hydromagnetic equations, energy principle and instabilities, applications to laboratory and space plasmas, introduction to controlled thermonuclear research. At the level of *Elementary Plasma Physics* by Longmire.

IMA622 Introductory Magnetohydrodynamics Spring, on demand. Credit three hours.
Basic equations of magnetohydrodynamics. Flow problems. Hydromagnetic shock waves. The pinch effect and instabilities. Tensor conductivity and excess electron temperature.

IMA704 Theory of Viscous Flows Spring. Credit three hours. Prerequisite: IMG632 or equivalent. S. F. Shen.
A systematic study of laminar flow phenomena and their methods of analysis, vorticity diffusion and flow development. Linear and nonlinear exact solutions of the Navier-Stokes equations. Linearized theory; viscous acoustics, the small Reynolds number approximation. Matched asymptotic expansion. The boundary layer equation and its general properties. Singular solution and the separation point. Transformations for compressibility and axisymmetric effects. Similar solutions; approximate methods of calculation. Three-dimensional and unsteady problems. Stability of laminar flows.

IMA706 Atmospheric Motions On demand. Credit three hours.
One-semester senior or graduate level course, emphasizing a mathematical and physical understanding of synoptic scale motions. The atmosphere; basic scales of synoptic motions; thermodynamics. Equations of motion; rotating and spherical coordinates. Geostrophic flow, the Rossby number, hydrostatic approximation, isobaric coordinates, balanced motions, thermal wind, prognostic equations. Circulation and vorticity; Ertel's theorem and potential vorticity. Planetary boundary layer; Reynolds stress, Ekman layer. Diagnostic equations; baroclinic motions. Sound, gravity, and Rossby waves. Analytical and

numerical models, filtered equations, baroclinic model, primitive equations. Cyclogenesis; fronts and frontogenesis. General circulation, energy and momentum, numerical simulation.

IMA707 Aerodynamic Noise Theory Spring, on demand. Credit three hours. Prerequisite: background in acoustics and fluid dynamics equivalent to IMF339 and IMF632–633 or consent of instructor.
Advanced topics in acoustics relevant to aerodynamic and transportation noise sources and control. Measurements and annoyance scales. Random processes. Geometrical acoustics in inhomogeneous moving media, Kirchhoff and Poisson formulas, diffraction, scattering. Lighthill-Curle formulations for sound generation. Moving sources. Jet, rotor, and boundary layer noise. Absorption and transmission in fluid and at boundaries.

IMA723 Special Topics in Plasma Physics Fall, alternate years on sufficient demand; scheduled for fall 1975. Credit three hours. Prerequisite: IMA621 or equivalent.
Advanced subjects of timely interest, at the level of current plasma physics literature or review articles. Recent topics have included radiation and scattering processes in plasmas, neoclassical transport theory, intense relativistic electron beam dynamics, and collision-free shock theory.

IMA792 Seminar in Aerospace Engineering
Credit two hours. Prerequisite: approval of the director.
Study and discussion of topics of current research interest in aerospace engineering.

IMA793 Plasma Physics Colloquium Fall and spring. Credit one hour.
Lectures by staff members, graduate students, and visiting scientists on topics of current interest in plasma research.

IMA795 Special Topics in Aerospace Engineering
Either term. Credit arranged. Prerequisite: consent of instructor.
Topics of current importance in aerospace engineering and research. Lecture or seminar format. More than one topic may be taken if offered.

IMA890–990 Research in Aerospace Engineering
Prerequisite: admission to the graduate Field of Aerospace Engineering and/or approval of the director.
Independent research in a field of aerospace science. Such research must be under the guidance of a member of the staff and must be of a scientific character.

Fluid Mechanics

IMF323 Fluid Mechanics Either term. Credit four hours. Four recitations. Prerequisites: IAK231 and IMG221.
Properties of fluids, fluid statics; kinematics of flow, elements of hydrodynamics; dynamics of flow, momentum and energy relations. Euler equations, wave motion; thermodynamics of flow; shocks and gas dynamics; dimensional analysis; real fluid phenomena, laminar and turbulent motion; compressible flow in ducts with area change, friction, and heating; laminar and turbulent layer, lift and drag; supersonic flow.

IMF439 Acoustics and Noise On demand. Credit three hours. Prerequisite: some knowledge of fluid mechanics or consent of instructor.
Vibration and wave motion. Plane sound waves: transmission and absorption. Spherical waves and sound radiation by surfaces and flow. Loudspeakers. Hearing, noise, and noise control criteria. Architectural acoustics and noise control techniques. At the level of *Fundamentals of Acoustics* by Kinsler and Frey.

IMF632 Fluid Mechanics I Fall. Credit three hours. Prerequisite: an elementary course in fluid mechanics or consent of instructor. S. Leibovich.
Introduction to the mechanics of fluids. Analysis of stress and deformation in fluids, derivation of the Navier-Stokes equations for incompressible fluids. Boundary conditions. Exact solutions. Vorticity theorems. Irrotational flows, method of images, distributions of singularities, complex variable techniques, axially-symmetric flows. Effects of rotation, the geostrophic approximation, Ekman layers. Boundary layer theory, exact methods of solution of the boundary layer equations.

IMF633 Fluid Mechanics II Spring. Credit three hours. Prerequisite: an elementary course in fluid mechanics or consent of instructor. S. Leibovich.
Approximate methods in boundary layer theory. Heat transfer. Buoyancy driven flows. Stability of fluid flow, Kelvin-Helmholtz instability, Rayleigh's stability theorems, Orr-Sommerfeld equations, nonlinear stability by the energy method. Introduction to turbulent flows, the Reynolds equations, turbulent scales, turbulence models. Dynamics of compressible flows, thermodynamics and the Navier-Stokes equations equations for a gas. Sound waves. Subsonic and supersonic flow. One dimensional steady flows, nozzle flows, Fanno and Rayleigh processes. One dimensional unsteady flows, method of characteristics, shock waves.

IMF636 Turbomachinery Fall. Credit three hours. Three recitations. Prerequisite: IMG221, IMF323, or consent of instructor. D. G. Shepherd.
Aerothermodynamic design of turbomachines in general, followed by consideration of specific types: fans, compressors, and pumps; steam, gas, and hydraulic turbines. Energy transfer between a fluid and a rotor; flow in channels and over blades. Compressible flow, three-dimensional effects, surging and cavitation. Outline design of a high-performance compressor-turbine unit.

IMF690 Special Investigations in Fluid Dynamics Fall and spring. Credit arranged. Permission required for registration.
Intended either for informal instruction of a small

number of students interested in work to supplement that given in regular courses or for a student wishing to pursue a particular investigation outside of regular courses.

IMF734 Turbulence and Turbulent Flow Fall, on demand. Credit three hours.
The structure of turbulence and methods of calculating turbulent flows. Topics will include mathematical descriptions of turbulence and experimental measurement tehniques; Reynolds stress, eddy viscosity and mixing length; structure of turbulence, including homogeneous isotropic turbulence, correlations and spectra, inertial and dissipation ranges, effects of shear and buoyancy, energy budget; recent developments in turbulent flow calculation methods.

IMF735 Dynamics of Rotating Fluids Fall, on demand. Credit three hours. Three lectures. Prerequisites: IMF312 and IAA682 or consent of instructor.
Review of classical fluid mechanics. Rotating coordinate systems. Linearized theory for rapidly rotating fluids. Inviscid regions, viscous layers. Large-amplitude steady motions past objects. Unsteady motions. Small amplitude and nonlinear waves in rotating fluids. "Vortex breakdown" in tornadoes and other swirling flows. Theories of vortex breakdown. Boundary layer interactions. Spin-up of fluids in rotating containers. A theoretical course designed for engineers and scientists interested in such applications as fluid motions in rotating containers, geophysical fluid mechanics, energy and mass separation in vortex tubes, etc. Some simple laboratory demonstrations of fundamental phenomena are included.

IMF737 Numerical Methods in Fluid Flow and Heat Transfer Spring. Credit three hours. Three recitations. Prerequisites: familiarity with the partial differential equations of fluid mechanics and basic FORTRAN programming. K. E. Torrance.
Finite-difference and finite-element methods are developed for solving multidimensional fluid flow and heat transfer problems. Basic principles are stressed throughout, enabling the methods to be extended to a wide range of physical problems involving convective and diffusive transport. Physical and numerical restraints imposed on transients and steady state numerical solutions are determined. Recent methods are surveyed and compared. Selected examples illustrate applications involving natural convection, flow over objects and within channels, planetary atmospheres and interiors, and flame spread. Assigned problems and the final examination require solution of fluid flow problems on a digital computer.

IMF738 Nonlinear Wave Propagation Spring, on demand. Credit three hours. Three lectures. Prerequisite: an acquaintance with the Fourier transformation and integration in the complex plane.
Emphasis is on mathematical treatment of nonlinear effects associated with waves in continua. The examples most completely treated will be taken from geophysical fluid dynamics and gas dynamics. Equations arising in other fields, such as nonlinear optics, will also be considered but in less detail. Topics: Fourier analysis of linear waves, phase and group velocity, dispersion, energy propagation, caustics, kinematic waves. Nonlinear hyperbolic systems characteristics, shock waves, energy dissipation. Burger's equation and its solution. Conservative dispersive systems. Exact solutions for the Korteweg-de Vries equation and other related nonlinear evolution equations. Nonlinear WKB approximation. Variational principles and Hamiltonian equations for nonlinear dispersive waves. Conservation of wave action. Nonlinear group velocity, resonant wave interactions, and instability of deep water waves.

Heat Transfer

IMH324 Heat Transfer and Transport Processes Either term. Credit three hours. One lecture, two recitations. Prerequisites: IMG221, IMF323.
Conduction of heat in steady-state, unsteady-state and periodic heat flow; analogic methods; numerical methods; fin surfaces; systems with heat sources. Convection; boundary layer fundamentals; natural convection; forced convection inside tubes and ducts; forced convection over various surfaces. Boiling and condensation. Radiation: emission, absorption, reflection, transmission, and exchanges. Radiation combined with conduction and convection. Heat exchangers; overall heat transfer coefficients; mean-temperature difference; effectiveness; design.

IMH650 Transport Processes I Fall. Credit three hours. Three recitations. Prerequisites: basic thermodynamics and fluid mechanics.
Description of modes of thermal and mass diffusion and transport. Formulation of the transport equations and their use in engineering and in environmental studies. Conduction and mass diffusion in solid materials. Thermal radiation exchange among assemblies of radiating bodies and as a diffusion process. Nature of nonopaque radiation interaction. Energy and mass diffusion by molecular and turbulent processes in convection. Regimes of transport. Consideration of convection resulting from buoyancy forces and from other forcing conditions in fluids. Various aspects of buoyancy-induced flows emphasized in relation to applications.

IMH651 Transport Processes II Spring. Credit three hours. Prerequisite: IMH650 or consent of instructor.
The diffusion of thermal energy, mass, and momentum is considered. Basic equations are reasoned in detail and applied to problems of current importance in technology and in environmental and ecological studies. Natural convection (buoyancy-induced) flows adjacent to surfaces and in freely rising plumes, buoyant jets, and thermals in extensive media (including stratified) are treated for laminar and for turbulent processes. Transient flows and the conversion of laminar motion to turbulent motion are treated. Thermal instability and the diffusion characteristics in naturally occurring bodies of fluid are studied. Forced flows and resulting convection are also considered; included are effects of property variation and viscous dissipation. Convective flow driven jointly by buoyancy forces and by imposed conditions, such as those in the atmosphere and adjacent to heated sur-

face, is discussed. Limits and mechanisms of these mixed flows are given.

IMH652 Seminar in Heat Transfer Spring. Credit three hours. Two-hour meetings weekly to be arranged. Prerequisite: consent of instructor.
Discussion of fields of active inquiry and current interest in heat transfer. Considerations of major recent work and several summaries of associated contributions.

Power, Advanced Thermodynamics, and Combustion

IMP304 The Nature of Thermodynamics Fall, on demand. Credit three hours. Three recitations. Prerequisite: a course in thermodynamics or consent of instructor. B. J. Conta.
History, philosophy, and mathematics of thermodynamics with emphasis on its scope and limitations. The methods of exposition of the concepts and laws of thermodynamics; a comparison of the intuitive, the axiomatic, and the statistical approaches. Principle rather than problem oriented; each student will be expected to develop a special topic in thermodynamics, present it orally, and write a term paper in place of a final examination.

IMP440 Thermodynamic Applications Fall. Credit three hours. Prerequisite: IMG221 or equivalent.
An introduction to a broad range of engineering applications of thermodynamics to cyclic and noncyclic processes. Heat engine or power cycles, both gas and vapor, steady flow and nonflow. Heat pump or refrigeration cycles, including thermoelectric and absorption refrigeration. Noncyclic energy conversion, with emphasis on combustion engines. The elements of chemical thermodynamics, including the Gibbs availability function and the special case of the Gibbs free energy, will be developed in order to establish the criteria of performance of combustion and other chemical engines. A brief treatment of fuel cells and an introduction to the thermodynamics of biological systems.

IMP442 Pollution Control in Power and Propulsion Spring. Credit three hours. Three recitations. Prerequisite: IMF323 concurrently, or consent of instructor. Staff.
The major sources of general power and motive power are also sources of air pollution, thermal pollution, and noise. Abatement techniques for these pollutants must be developed if we are to satisfy demands for more power while preserving our environment. An introduction to the major problems associated with each of these types of pollution and to possible methods of control; fundamental technical aspects of the problems and their solution. Introduction to the various engineering sciences which form a basis for control technologies.

IMP449 Combustion Engines Fall. Credit three hours. Three recitations. Prerequisite: IMG221 or IMG221 concurrently.
Introduction to combustion engines with emphasis on application of thermodynamics and fluid dynamics, and on minimization of harmful exhaust emissions. Reciprocating combustion engines, including the stratified charge engine; rotary engines.

IMP643 Combustion Processes Spring. Credit three hours. Three recitations. Prerequisites: basic thermodynamics, fluid mechanics, and heat transfer.
An introduction to combustion and flame processes with emphasis on the rate-controlling effects of fluid dynamics, heat and mass transfer, and reaction kinetics. Topics include classification of fuels; heat of combustion and flame temperature; mixture equilibrium; combustion in homogeneous mixtures; deflagrations, detonations, and explosions; ignition, quenching, and burning limits; flame stabilization; turbulent burning; diffusion flames; and burning of droplets and particles.

IMP648 Seminar on Combustion Spring. Credit three hours. Meetings three times a week to be arranged. Prerequisite: consent of instructor. F. C. Gouldin, W. J. McLean, K. E. Torrance.
Discussion of contemporary problems in combustion, such as combustion-generated air pollution, destructive fires, and fuels for future combustion systems. Emphasis will be placed on the experimental and analytical tools required for current combustion research. Topics include numerical techniques, turbulence modeling, temperature and composition measurements, and laser applications.

IMP655 Energy Conversion Spring. Credit three hours. Three lectures. Prerequisite: IMG221 or equivalent.
Primarily a survey of methods for the direct conversion of heat into electrical energy, with emphasis on efficiency, maximum power, practical applications, and limitations. Thermoelectric generators and refrigerators. Thermionic generators. Solar cells. Magneto-fluid-dynamic generators. Fuel cells. Other possible methods for direct energy conversion. Methods of energy storage.

IMP656 Power Systems I Fall. Credit three hours. Prerequisites: IMG221 and IMF323 or equivalent.
A broad survey of methods of large-scale power generation, emphasizing energy sources, thermodynamic and fluid mechanical cycle considerations, and component description. Power industry, economic, and environmental factors. Long-range trends and projections. Fossil-fueled steam-turbine systems. Exhaust emissions, cooling problems and methods. Peak load problems; gas turbine, energy storage schemes. Topping units, binary cycles, MHD.

IMP657 Power Systems II Spring. Credit three hours. F. K. Moore.

IMP658 Processes of Large Scale Heat Rejection. Fall, on demand. Credit three hours. Three recitations. Prerequisites: IMF323 and IMH324 concurrently; or equivalent preparation in fluid mechanics and heat transfer. F. K. Moore.
Application of fluid mechanics and heat transfer to the analysis of problems of large-scale heat rejection. The development of plumes and the effects of heat

rejection on temperature cycles of water bodies. Performance and size estimation of cooling towers of evaporative and dry types, including the role of heat exchanger design in such cooling systems for large power plants. The effects of large-scale heat rejection on the planetary boundary layer. Dispersion of thermal effluents in the atmosphere. Urban heat islands and regional warming. Discussion of present and future trends in the development of heat dispersal methods.

IMP690 Special Investigations in Power, Thermodynamics, or Combustion Fall and spring. Credit by arrangement. Intended either for informal instruction of a small number of students interested in work to supplement that given in regular courses or for a student wishing to pursue a particular investigation outside of regular courses. Permission required for registration.

Operations Research

See course descriptions for *Industrial Engineering and Operations Research*, p. 104.

Structural Engineering

See course descriptions under *Civil and Environmental Engineering*, p. 78.

Theoretical and Applied Mechanics

Courses in theoretical and applied mechanics are listed under the following headings: *For Undergraduates Only, Engineering Mathematics, Mechanics of Solids, Dynamics and Vibrations, Experimental Mechanics, Space Mechanics, Biomechanics, and Special Courses.*

For Undergraduates Only

Mathematics 293, 294, 295, 296 Engineering Mathematics See entries under Division of Basic Studies.

IAK105 Finite Mathematics for Biologists (Same as Mathematics 105.) Offered by the Department of Mathematics 1975–76. Fall. Credit three hours, plus optional fourth hour for introduction to computing. Two lectures, plus two hours to be arranged; evening examinations. Prerequisite: three years of high school mathematics, including trigonometry.
Models, analytic geometry, difference equations, elementary linear algebra, probability. Optional introduction to interactive computing. Examples from biology are used throughout the course.

IAK106 Calculus for Biologists (Same as Mathematics 106.) Offered by the Department of Mathematics 1975–76. Spring. Credit three hours. Two lectures plus two hours to be arranged; evening examinations. Prerequisite: Mathematics 105 or three years of high school mathematics, including trigonometry and analytic geometry.
Introduction to differential and integral calculus, partial derivatives, elementary differential equations. Examples from biology are used throughout the course.

IAK201 Introduction to Applied Mechanics Either term. Credit three hours. Two lectures, one recitation per week; four laboratory sessions per term. Prerequisite: registration in Mathematics 293.
See description in entry under Division of Basic Studies.

IAK221 Mechanics of Solids Either term. Credit three hours. Two lectures, one recitation; laboratory participation four times per term. Prerequisite: registration in Mathematics 293.
See description in entry under Division of Basic Studies.

IAK231 Dynamics Either term. Credit three hours. Two lectures, one recitation; laboratory participation four times per term. Prerequisite: registration in Mathematics 294.
See description in entry under Division of Basic Studies.

Engineering Mathematics

IAA350 Advanced Engineering Analysis I Fall. Credit three hours. Prerequisite: Mathematics 294 or equivalent. Two lectures.
Methods of applied mathematics as they arise in a systematic study of problems in engineering which give rise to ordinary differential equations. Topics include infinite series, uniform convergence, Bessel's Legendre, and gamma functions, numerical methods, matrix algebra, initial-value problems, boundary-value problems, and eigenvalue problems in ordinary differential equations. At the level of *Mathematics of Physics and Modern Engineering* by Sokolinkoff and Redheffer.

IAA351 Advanced Engineering Analysis II Spring. Credit three hours. Prerequisite: IAA350 or equivalent.
A continuation of IAA350, with emphasis on methods of analysis which arise in a systematic study of partial differential equations. Topics include functions of several variables, vector field theory, Fourier series, classical methods for partial differential equations, introduction to numerical methods, classification, and complex variables. Applications to heat flow, stress analysis, and gas dynamics.

IAA680 Methods of Applied Mathematics Fall. Credit three hours. Three lectures. Open to graduate students or to undergraduates with consent of instructor. Intended for students who plan to use

applied mathematics frequently; many students will supplement it with IAA681–683.
Ordinary differential equations, series, orthogonal functions and Sturm-Liouville theory, functions of several real variables, vector fields and integral theorems, matrices, partial differential equations. Emphasis on applications and techniques of solution, wherever possible. At the level of *Mathematics of Physics and Modern Engineering* by Sokolnikoff and Redheffer.

IAA681 Methods of Applied Mathematics II Spring. Credit three hours. Three lectures. Prerequisite: IAA681 or equivalent.
Continuation of partial differential equations, separation of variables, Green's functions, Fourier and Laplace transforms, complex variables through the theory of residues, calculus of variations, including Rayleigh-Ritz method, tensor analysis.

IAA682 Methods of Applied Mathematics III Fall. Credit three hours. Two lectures. Prerequisite: IAA681 or equivalent. G. S. S. Ludford.
Application of advanced mathematical techniques to engineering problems. Review of complex variable theory, conformal mapping, and complex integral calculus; integral transforms for partial differential equations; Green's function; asymptotics, including steepest descent and stationary phase; Wiener-Hopf technique; nonlinear partial differential equations; general theory of characteristics; singular perturbations and boundary layers. Problems drawn from vibrations and acoustics, fluid mechanics and elasticity, heat transfer, and electromagnetics.

[**IAA684 Numerical Methods in Engineering** Spring, alternate years. Credit three hours. Prerequisite: IAA681 or equivalent. Not offered 1975–76.
Methods for obtaining numerical solutions to problems arising in engineering. Linear and nonlinear mechanical systems. Ordinary and partial differential equations, initial-value problems, boundary-value problems, eigenvalue problems, and extrema. Calculus of variations. Function-space methods. Applications to vibrations, diffusion, heat transfer, wave propagation, membranes, plates, fluid flow, and celestial mechanics. Simulation of dynamical systems. Analog computation.]

IAA685 Methods of Applied Mathematics IVa Spring. Credit two hours. Prerequisite: IAA682 or equivalent.
In context of applications: regular and singular perturbation theory, method of matched asymptotic expansions, two timing (method of multiple scales), WKB approximation.

IAA686 Methods of Applied Mathematics IVb Spring. Credit two hours. Prerequisite: IAA682 or equivalent.
In context of applications: Hilbert-Schmidt and Fredholm theories of integral equations, singular integral equations, Wiener-Hopf equations with application to finite interval, Carleman equation and its generalization, effective approximations.

Mechanics of Solids

[**IAB610 Introduction to Continuum Mechanics** Fall, alternate years. Credit three hours. Three lectures. J. T. Jenkins. Not offered 1975–76.
Introduction to the physical aspects of modern continuum mechanics, providing a foundation for further studies in fluid and solid mechanics, materials science, and other branches of engineering. Vectors and tensors. Analysis of stress and strain. Deformation. Constitutive equations. Balance principles and the derivation of field equations. Examples from fluid dynamics and elasticity.]

IAB663 Applied Elasticity Fall. Credit three hours. Two lectures. H. D. Conway.
Analysis of thin curved bars. Plane stress and plane strain in the circular cylinder; effects of pressure, rotation and thermal stress. Small- and large-deflection theory of plates, classical and approximate methods. Strain-energy methods. Symmetrically loaded thin cylindrical shell. Torsion of thin walled members. A first course in the mechanics of elastic deformable bodies with structural applications.

IAB664 Theory of Elasticity Spring. Credit three hours. Three lectures. H. D. Conway.
General analysis of stress and strain. Plane stress and strain. Airy's stress function solutions using Fourier series, Fourier integral, and approximate methods. St. Venant and Michell torsion theory. Simple three-dimensional solutions. Bending of prismatical bars. Axially loaded circular cylinder and half space.

[**IAB765 Mathematical Theory of Elasticity** Spring, alternate years. Credit three hours. Three lectures. Prerequisites: IAB663 and IAB664. J. T. Jenkins. Not offered 1975–76.
Development in tensor form of the basic equations of large-deformation elasticity; solution of certain large-deformation problems. Linearization to infinitesimal elasticity. Boussinesq-Papkovich potentials and their application to three-dimensional problems; contact problems; plane stress by method of Muskhelishvili; application of conformal mapping; Cauchy integral techniques in elasticity; torsion problems.]

IAB766 Dynamic Theory of Elasticity Spring, alternate years. Credit three hours. Two 1½-hour lectures. Prerequisites: IAC664 and IAB663 or equivalent. Y. H. Pao.
An advanced course on dynamic stress analysis and wave propagation in elastic solids. General equations of elastodynamics. Waves in extended elastic media. Reflection and refraction. Surface waves and waves in layered media. Generation of waves by explosive sources and dynamic loadings. Methods of Lamb-Cagniard-Pekeris and the generalized rays. Dispersion of waves in plates and rods. Thick plate theories. Vibration of spheres. Scattering of waves and dynamic stress concentration. Waves in anisotropic media.

[**IAB668 Theory of Plasticity** Fall. Credit three hours. Not offered 1975–76.
Theory of inelastic behavior of materials. Plastic

stress-strain laws, yield criteria, flow rules. Work hardening. Flexure and torsion of bars. Thick cylinders and spheres. Limit analysis of structure. Plane strain-slip line theory.]

IAB790 Continuum Mechanics and Thermodynamics Fall, alternate years. Credit three hours. Three lectures. J. T. Jenkins.
Kinematics. Conservation laws. The entropy inequality. Constitutive equations. Frame indifference. Material symmetry. Simple materials and the position of classical theories in the framework of modern continuum mechanics.

IAB791 Topics in Continuum Mechanics Spring. Offered in alternate years. Credit three hours. Three lectures. Prerequisite: IAB790. J. T. Jenkins.
Theory of (nonlinear) elasticity and thermoelasticity; universal solutions, wave propagations, and stability theory. Nonlinear viscoelastic fluids and solids. Viscometric flows. Materials with continuum microstructure.

Dynamics and Vibration

IAC664 Mechanical Waves and Vibrations Spring. Offered in alternate years. Credit four hours. Two 1½-hour lectures, one laboratory.
An introduction to a unified treatment of waves and vibrations in elastic systems, including strings, rods, beams, membranes, and plates. Acoustic waves in air and solids, and seismic waves. Dispersion and group velocity. Transient waves and forced vibrations. Moving loads and sources. Plane, cylindrical, and spherical waves. Huygen's principle. Radiation and scattering. Mechanical wave guides. At the level of *Analytical Methods in Vibrations* by Mierovitch, and *Mechanical Radiation* by Lindsay.

IAC670 Intermediate Dynamics Fall. Credit three hours. Two 1½-hour lectures. For graduate students or advanced undergraduate students with consent of instructor.
Newtonian mechanics for single particles and systems of particles, conservation laws, central-force motion; rigid-body mechanics, Euler's equations, tops, gyroscopes; generalized coordinates, introduction to Lagrangian mechanics, Hamilton's principle. Text: *Principles of Dynamics* by Greenwood.

IAC771 Advanced Dynamics Spring. Credit three hours. Prerequisite: IAC670 or equivalent.
Hamilton's principle, Lagrangian mechanics, principle of least constraint, principle of least action, Gibbs-Appell equations; Hamilton's equations, canonical transformations, Hamilton-Jacobi theory; differential geometry of geodesics; general theory of orbits; topological dynamics.

[**IAC675 Nonlinear Vibrations** Spring. Credit three hours. Three lectures. Prerequisite: IAC662 or equivalent. Not offered 1975–76.
Phase-plane techniques, singular points, conservative systems, limit cycles. Poincaré-Bendixson theorem, Poincaré's cycles without contact, method of isoclines, Lienard's method, Lyapunov stability, Floquet theory, Hill's and Mathieu's equation, perturbation methods, method of Krylov and Bogoliubov. Applications.]

IAC676 Stability of Motion Spring. Credit three hours. Three lectures.
Physical notions of stability, Lyapunov stability, orbital stability, Lyapunov's second method, validity of linearized variational equations, stability of equilibrium points, stability of periodic motions. Floquet theory, perturbations, structural stability, Poisson stability, ergodicity.

IAC699 Fundamentals of Acoustics (Same as Electrical Engineering IEE399.) Spring. Credit three hours. Three lectures, six laboratories per term. W. S. Sachse.
Introduction to the principles and theories of acoustics to permit an understanding of the generation, propagation, detection, and measurement of acoustic phenomena. Topics included are: the vibrations of strings, bars, membranes, and plates; plane and spherical acoustic waves; transmission phenomena; resonators and filters; the propagation of acoustic waves in solids and fluids. Application is made to sonic and ultrasonic transducers, music and noise, and architectural acoustics. At the level of *Fundamentals of Acoustics* by Kinsler and Frey.

Experimental Mechanics

IAD659 Experimental Mechanics Fall. Credit three hours. Two lectures. W. H. Sachse.
The student is expected to perform four to six classical experiments in mechanics selected to meet his or her individual interests. Available experiments include: elastic waves in rods, viscoelastic waves and internal damping, linear vibrations of beams and plates, mechanical properties of materials, photoelasticity, plastic response of structures, gyroscopic motion, linear oscillators, and analog computers.

Space Mechanics

[**IAG672 Space Flight Mechanics** (Same as Astronomy 579.) Fall, alternate years. Credit three hours. Not offered 1975–76.
Gravitational potential of the earth, two-body problem, three-body problem, restricted three-body problem, Jacobi's integral, Hill curves, libration points and stability, capture problems. Lagrange's planetary equations; effect of oblate earth, atmospheric drag, and solar radiation on satellite orbits; satellite attitude control; orbital maneuvers, rendezvous problems.]

[**IAG673 Mechanics of the Solar System** (Same as Astronomy 571.) Fall, alternate years. Credit three hours. Three lectures. Prerequisite: IAC670 or consent of instructor. J. A. Burns. Not offered 1975–76.
Application of the principles of mechanics to explain physical phenomena in the solar system. An understanding of the interplanetary environment will be developed. Topics include: geophysical principles and ideas as applied to Earth and other planets; seismic

waves, free oscillations, free and forced rotation, gravitational potentials. Equilibrium tidal theory, tidal interactions, orbital evolution of the earth-moon system, spin-orbit coupling of Mercury and Venus. Dynamical characteristics of comets and asteroids. Dust dynamics; radiation pressure, Poynting-Robertson drag; Yarkovsky effect. Relativistic perihelion precession of Mercury.]

Biomechanics

IAH601 Introduction to Biomechanics, Bioengineering, Bionics, and Robots Fall. Credit three hours. Three lectures. Prerequisites: elementary differential equations, linear algebra, and probability; or consent of instructor. A lecture course intended primarily for undergraduates. An introduction to IAH692, but not necessarily a prerequisite. H. D. Block.
Bionics, the general subject, is the study of possible applications of techniques used by living organisms to the design of engineering devices. Examples are how birds fly, fish swim, and men run; and how animals see, hear, learn, recognize, recall, guess, and reason. The possibility of designing robots to operate in ways analogous to physiological and mental functions will be explored. Typical areas: developments in biomedical engineering, artificial intelligence, pattern recognition, natural languages, neural network and brain models, philosophical questions of computers and the foundations of mathematics, theoretical aspects of competitive and evolutionary ecological systems, biodynamics, and progress in the augmentation of human muscular and mental power. Students interested in particular areas may do individual or team work consisting of study, research, design, or construction.

IAH666 Pattern Classification Spring, alternate years. Credit three hours. Prerequisite: IOA260–270 or equivalent background in probability and statistics. J. C. Dunn.
Graph theoretic and criterion function clustering techniques. Clustering methods based on the theory of fuzzy sets. Linear and nonlinear categorizers. Error correcting procedures. Group averaging techniques and feature extraction. Applications to biological taxonomy, automated character recognition, medical diagnosis.

[**IAH692 Current Research Problems in Bionics and Robots** Spring, alternate years. Credit one to four hours, as arranged in prior consultation with staff. IAH601 is introductory but is not necessarily a prerequisite. H. D. Block. Not offered 1975–76.
A graduate-level seminar, concentrating on a few of the topics listed under IAH601. Faculty and students report on current research articles, papers, books, and personal investigations in such areas as: robots designed to learn natural language, artificial intelligence, pattern recognition and scene analysis by machine, evolutionary systems, biodynamics, adaptive control, and brain and behavior models.]

Special Courses

IAJ704–705 Seminar in Fluid Mechanics Fall and spring. Credit three hours. Prerequisite: consent of instructor. G. S. S. Ludford.
Study and discussion of topics of current research interest in the field of fluid mechanics. Participants prepare and deliver reports based on published and unpublished literature.

IAJ821–822 Project in Mechanics Fall and spring. Credit to be arranged.
A minimum of three credit hours must be completed by each candidate for the Master of Engineering (Engineering Mechanics) degree.

IAJ896 Research in Theoretical and Applied Mechanics Either term. Credit as arranged.
Thesis, literature survey, or independent research on a subject of theoretical and applied mechanics. Research will be under the guidance of a staff member.

IAJ897 Selected Topics in Theoretical and Applied Mechanics Either term. Credit as arranged.
Special lectures or seminars on subjects of current interest in the Field of Theoretical and Applied Mechanics. Topics will be announced when the course is offered.

Reference List of Current and Former Course Numbers

(Courses with no "old" numbers are omitted.)

Agricultural Engineering

New	Old	New	Old	New	Old	New	Old
325	421	471	471	552	552	685	504
401	450	475	475	651	501	700	601
415	410	481	481	652	502	761	602
416	411	482	482	675	505	771	603
461	461	491	491	676	506	775	605
462	462	492	492	677	507	781	604
465	463	551	551	678	510	785	606

Applied and Engineering Physics

New	Old	New	Old	New	Old	New	Old
IP201	8301	IP456	8156	IP613	8313	IP652	8352
IP217	8117	IP461	8161	IP619	8509	IP705	8505
IP303	8303	IP490	8090	IP621	8511	IP711	8211
IP306	8606	IP601	8601	IP622	8512	IP712	8212
IP323	8123	IP603	8603	IP623	8513	IP751	8051
IP333	8133	IP605	8605	IP633	8333	IP752	8052
IP355	8155	IP606	8506	IP634	8334	IP753	8252
IP401	8501	IP607	8507	IP636	8336	IP761	8261
IP424	8124	IP609	8309	IP651	8351	IP762	8262
IP434	8134	IP612	8312				

Chemical Engineering

New	Old	New	Old	New	Old	New	Old
IHE101	5041	IHE462	5624	IHE641	5743	IHE683	5852
IHE110	5111	IHE565	5627	IHE642	5752	IHE692	5952
IHE111	5101	IHE595	5955	IHE643	5770	IHE693	5953
IHE311	5102	IHE596	5956	IHE644	5748	IHE694	5954
IHE312	5103	IHE611	5161	IHE645	5749	IHE711	5105
IHE321	5257	IHE621	5741	IHE648	5744	IHE712	5107
IHE410	5106	IHE625	5636	IHE651	5510	IHE713	5109
IHE430	5304	IHE627	5760	IHE671	5717	IHE714	5508
IHE431	5305	IHE628	5641	IHE672	5750	IHE731	5505
IHE432	5353	IHE630	5312	IHE680	5851	IHE751	5501
IHE433	5354	IHE631	5609	IHE681	5857	IHE790	5900
IHE461	5623	IHE640	5742	IHE682	5859		

Civil and Environmental Engineering

New	Old	New	Old	New	Old	New	Old
IIA153	2153	IIB303	2203	IIC617	2317	IID712	2412
IIA380	2180	IIB615	2215	IIC618	2318	IID714	2414
IIA661	2161	IIB616	2216	IIC620	2320	IID715	2415
IIA662	2162	IIB617	2217	IIC621	2321	IID718	2418
IIA671	2171	IIB618	2218	IIC691	2391	IID792	2492
IIA685	2185	IIB619	2219	IIC693	2393	IIE301	2501
IIA686	2186	IIB651	2651	IIC694	2394	IIE602	2502
IIA687	2187	IIB693	2293	IIC716	2316	IIE610	2510
IIA688	2188	IIB747	2247	IIC792	2392	IIE611	2511
IIA689	2189	IIB780	2280	IID301	2401	IIE613	2513
IIA691	2191	IIB791	2291	IID606	2406	IIE614	2514
IIA692	2192	IIB792	2292	IID610	2410	IIE620	2520
IIA693	2193	IIB794	2294	IID616	2416	IIE630	2530
IIA694	2194	IIC301	2301	IID631	2431	IIE633	2533
IIA696	2196	IIC302	2302	IID632	2432	IIE634	2534
IIB201	2201	IIC609	2309	IID691	2491	IIE693	2593
IIB202	2202	IIC612	2312	IID693	2493	IIE791	2591
IIB205	2205	IIC615	2315	IID694	2494	IIE792	2592

IIE794	2594	IIF794	2694	IIG711	2711	IIG791	2791
IIF620	2620	IIG301	2701	IIG712	2712	IIG792	2792
IIF621	2621	IIG302	2702	IIG713	2713	IIG794	2794
IIF622	2622	IIG303	2703	IIG714	2714	IIH615	2815
IIF623	2623	IIG304	2704	IIG715	2715	IIH616	2816
IIF624	2624	IIG305	2705	IIG716	2716	IIH718	2818
IIF640	2640	IIG351	2751	IIG717	2717	IIH731	2831
IIF641	2641	IIG652	2752	IIG718	2718	IIK502	2002
IIF643	2643	IIG653	2753	IIG719	2719	IIK510	2010
IIF644	2644	IIG654	2754	IIG720	2720	IIK511	2011
IIF791	2691	IIG655	2755	IIG722	2722	IIK520	2020
IIF792	2692	IIG690	2790	IIG732	2732	IIK521	2021
IIF793	2693	IIG693	2793	IIG757	2757	IIK801	2001

Computer Science

New	*Old*	*New*	*Old*	*New*	*Old*	*New*	*Old*
ICS100	100	ICS414	404	ICS632	632	ICS727	527
ICS101	201	ICS481	485	ICS635	635	ICS729	621
ICS102	311	ICS482	486	ICS641	441	ICS733	733
ICS104	104	ICS611	411	ICS681	588	ICS734	734
ICS105	305	ICS612	412	ICS682	587	ICS739	635
ICS106	106	ICS613	413	ICS709	591	ICS781	488
ICS211	202	ICS615	415	ICS712	487	ICS782	589
ICS280	203	ICS616	416	ICS719	611	ICS789	681
ICS314	401	ICS618	517	ICS721	521	ICS790	590
ICS321	321	ICS621	421	ICS723	523	ICS890	590
ICS322	322	ICS622	422	ICS725	525	ICS990	590
ICS410	409						

Electrical Engineering

New	*Old*	*New*	*Old*	*New*	*Old*	*New*	*Old*
IEE311	4301	IEE620	4450	IEE674	4484	IEE734	4534
IEE312	4302	IEE621	4453	IEE675	4487	IEE735	4535
IEE313	4311	IEE623	4475	IEE676	4488	IEE736	4536
IEE314	4312	IEE624	4478	IEE677	4587	IEE737	4631
IEE315	4321	IEE625	4575	IEE678	4588	IEE738	4632
IEE316	4322	IEE627	4571	IEE680	4464	IEE761	4507
IEE401	4401	IEE628	4572	IEE681	4561	IEE762	4508
IEE410	4410	IEE631	4433	IEE682	4564	IEE763	4674
IEE411	4411	IEE632	4434	IEE683	4511	IEE764	4672
IEE430	4430	IEE633	4437	IEE684	4514	IEE765	4673
IEE432	4412	IEE634	4438	IEE685	4551	IEE771	4505
IEE531	4431	IEE635	4537	IEE686	4552	IEE772	4506
IEE532	4432	IEE651	4445	IEE687	4565	IEE773	4681
IEE551	4441	IEE652	4446	IEE688	4566	IEE781	4661
IEE552	4442	IEE661	4473	IEE721	4503	IEE791	4691
IEE581	4461	IEE662	4474	IEE722	4504	IEE792	4692
IEE582	4462	IEE663	4476	IEE731	4531	IEE793	4595
IEE591	4591	IEE671	4481	IEE732	4532	IEE794	4596
IEE592	4592	IEE672	4482	IEE733	4533	IEE795-799	4700-4800

Geological Sciences
(All numbers remain the same.)

Industrial Engineering and Operations Research

New	*Old*	*New*	*Old*	*New*	*Old*	*New*	*Old*
IOR213	9113	IOR350	9350	IOR437	9337	IOR622	9522
IOR260	9160	IOR361	9361	IOR471	9371	IOR623	9523
IOR270	9170	IOR370	9370	IOR516	9526	IOR625	9525
IOR301	9301	IOR383	9383	IOR551	9551	IOR630	9530
IOR320	9320	IOR410	9410	IOR562	9562	IOR631	9531
IOR321	9321	IOR421	9521	IOR570	9512	IOR632	9532
IOR335	9135	IOR435	9335	IOR614	9514	IOR633	9533

IOR634	9534	IOR672	9572	IOR741	9541	IOR789	9589
IOR635	9535	IOR674	9571	IOR761	9561	IOR890	9590
IOR637	9537	IOR680	9580	IOR764	9564	IOR891	9591
IOR640	9540	IOR682	9582	IOR769	9569	IOR893	9593
IOR660	9460	IOR736	9536	IOR773	9573	IOR894	9594
IOR661	9560	IOR738	9538	IOR774	9574	IOR898	9598
IOR670	9470	IOR739	9539	IOR779	9579	IOR899	9599
IOR671	9570						

Materials Science and Engineering

New	*Old*	*New*	*Old*	*New*	*Old*	*New*	*Old*
ITE201	6101	ITE440	6040	ITE701	6601	ITE714	6614
ITE261	6261	ITE441	6041	ITE702	6602	ITE725	6625
ITE262	6262	ITE443	6043	ITE703	6603	ITE762	6762
ITE331	6031	ITE444	6044	ITE704	6604	ITE763	6763
ITE333	6033	ITE445	6045	ITE705	6605	ITE765	6765
ITE334	6034	ITE446	6046	ITE706	6606	ITE767	6767
ITE335	6035	ITE448	6048	ITE707	6607	ITE768	6768
ITE336	6036	ITE553	6553	ITE712	6612	ITE769	6769
ITE339	6039	ITE554	6554				

Mechanical and Aerospace Engineering

New	*Old*	*New*	*Old*	*New*	*Old*	*New*	*Old*
IMA602	7302	IMD663	3363	IMG302	3020	IMP449	3669
IMA603	7303	IMD672	3372	IMG325	3325	IMP643	3652
IMA611	7101, 3667	IMD674	3374	IMG453	3053	IMP648	3668
IMA612	7612	IMD680	3380	IMG654	3654	IMP655	3672
IMA613	7102	IMD690	3390	IMG656	3656	IMP656	3641
IMA621	7201	IMD692	3392	IMG790	3090	IMP658	3691
IMA622	7202	IMF230	3622	IMG791	7801	IMP690	3690
IMA704	7304	IMF323	3623	IMG799	7901	IMS326	3326
IMA705	7305	IMF339 and		IMG890	3098	IMS389	3333
IMA706	7306	IMF439	3639	IMG990	3099	IMS677	3368
IMA707	7307	IMF632	3632	IMH324	3625	IMS678	3378
IMA713	7103	IMF633	3633	IMH650	3665	IMS679	3388
IMA723	7203	IMF636	3663	IMH651	3680	IMS682	3382
IMA792	7902	IMF690	3690	IMH652	3682	IMS685	3385
IMA793	7903	IMF734	7308	IMM311	3401	IMS690	3390
IMA795	7905	IMF735	3675	IMM612	3451	IMS770	3361
IMA890-990	7801	IMF737	3677	IMM614	3475	IMS771	3371
IMB562	3362	IMF738	3685	IMM690	3490	IMT305	7001
IMB665	3365	IMG101	3301	IMP304	3659	IMT486	3377
IMB690	3690	IMG208	3208	IMP440	3640	IMT606	3671
IMD464	3364	IMG221	3631	IMP442	3642	IMT687	3387

Theoretical and Applied Mechanics

New	*Old*	*New*	*Old*	*New*	*Old*	*New*	*Old*
IAA350	1150	IAB664	1264	IAC676	1376	IAJ705	1905
IAA351	1151	IAB667	1267	IAC699	1399	IAJ821	1921
IAA680	1180	IAB668	1268	IAC771	1371	IAJ822	1922
IAA681	1181	IAB680	1280	IAC781	1381	IAJ896	1996
IAA682	1182	IAB765	1265	IAD659	1459	IAJ897	1997
IAA684	1184	IAB766	1266	IAD660	1460	IAK105	1005
IAA685	1183a	IAB771	1271	IAG672	1772	IAK106	1006
IAA686	1183b	IAB790	1290	IAG673	1773	IAK201	1001
IAA770	1170	IAB791	1291	IAH601	1801	IAK221	1021
IAA771	1171	IAC664	1364	IAH692	1892	IAK222	1022
IAB610	1210	IAC670	1370	IAJ704	1904	IAK231	1031
IAB663	1263	IAC675	1375				

Cornell University

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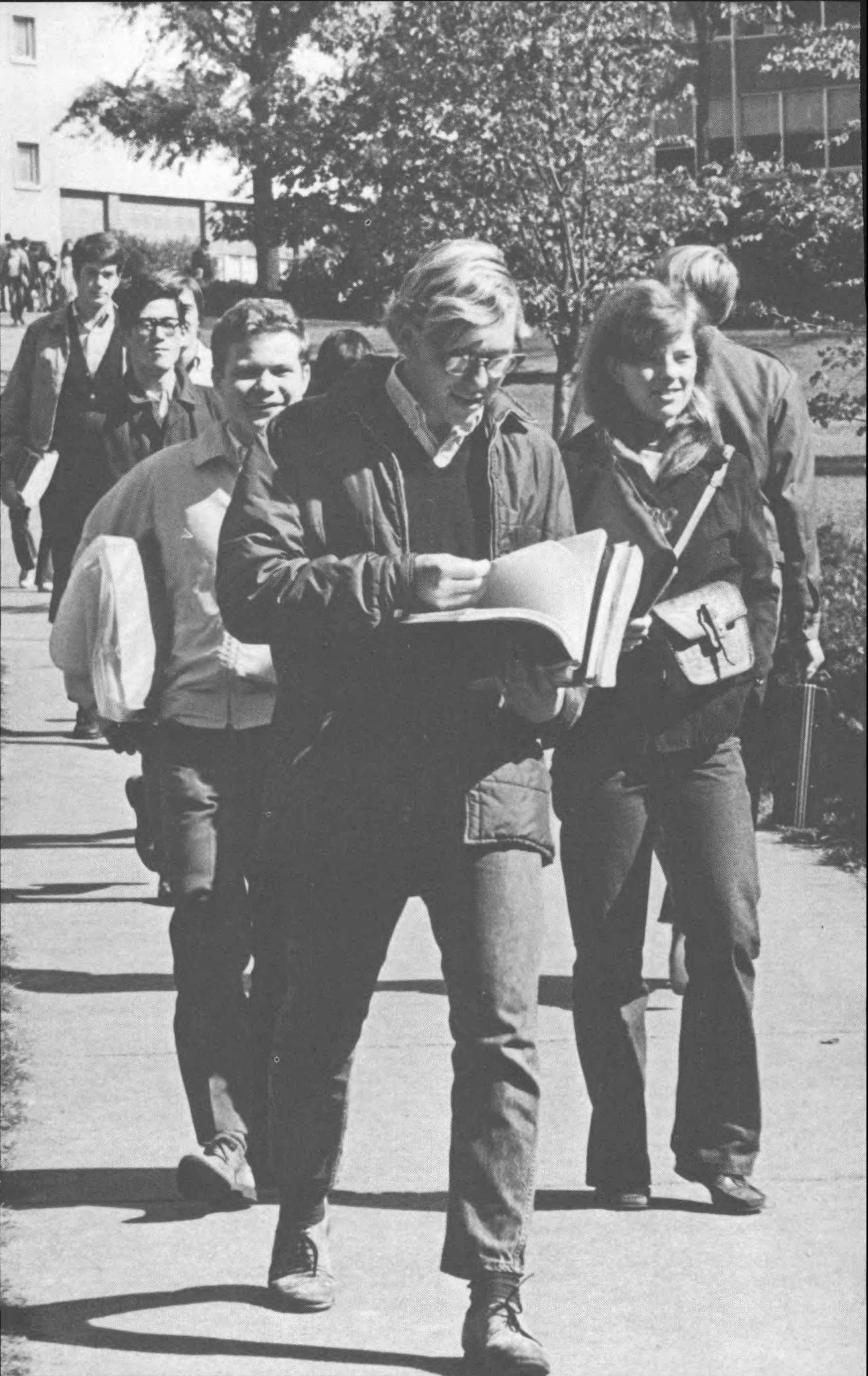

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